Distributed Energy Resources (DER)

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Introduction – What is a Distributed Energy Resource (DER)

A DER is a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load.

*Examples of different types of DER include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE).**

* IEEE 1547 Standard specifically omits DR and other "loads" as part of the DER definition. It focuses on sources of generation tied to distribution systems.

* NARUC Design Manual (https://www.naruc.org/rate-design/)

DER action is coming…
from NERC and FERC

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"NERC and the industry [must] understand DER functionality and develop a set of guidelines to assist in modeling and assessments such that owners/operators of the [bulk power system] can evaluate and model DER in the electric system."

– NERC DER Task Force, February 2017

FERC is working on rules for market participation of electric storage and aggregated DER, reforming generator interconnection procedures & agreements, and further evolution of PURPA.

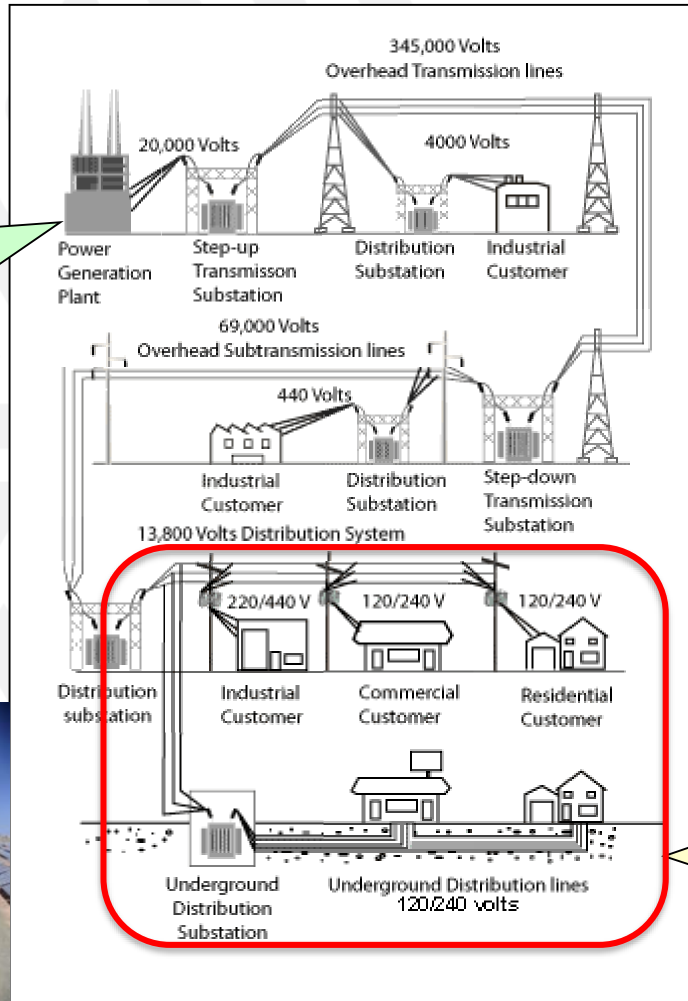
Source: Tom Stanton, NRRI

Where do DER Connect?

Transmission Connected Generation

Large wind farms, CSP, utility-scale PV, biopower, hydro, geothermal, interconnect at transmission level

Electric Power System



Photos: NREL PIX Library

Distribution Connected Generation (DER)

Photovoltaic systems, small wind, storage & fuel cells interconnect at the distribution level – Behind the Substation

Examples of DERs

- Photovoltaic
- Battery Storage
- Small Hydro
- Small Wind
- Fuel Cells
- Demand Response
- Electric Vehicles & V2G
- Smart Buildings

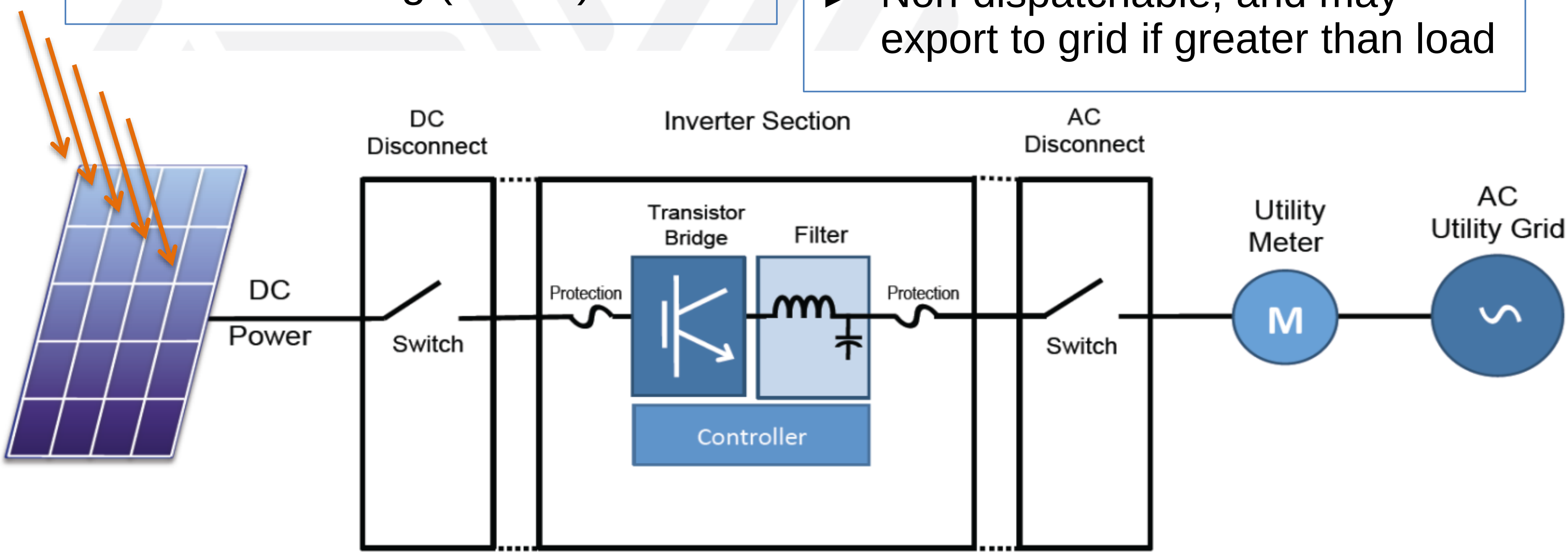
Source: NREL Pix

Photovoltaic Systems (PV)

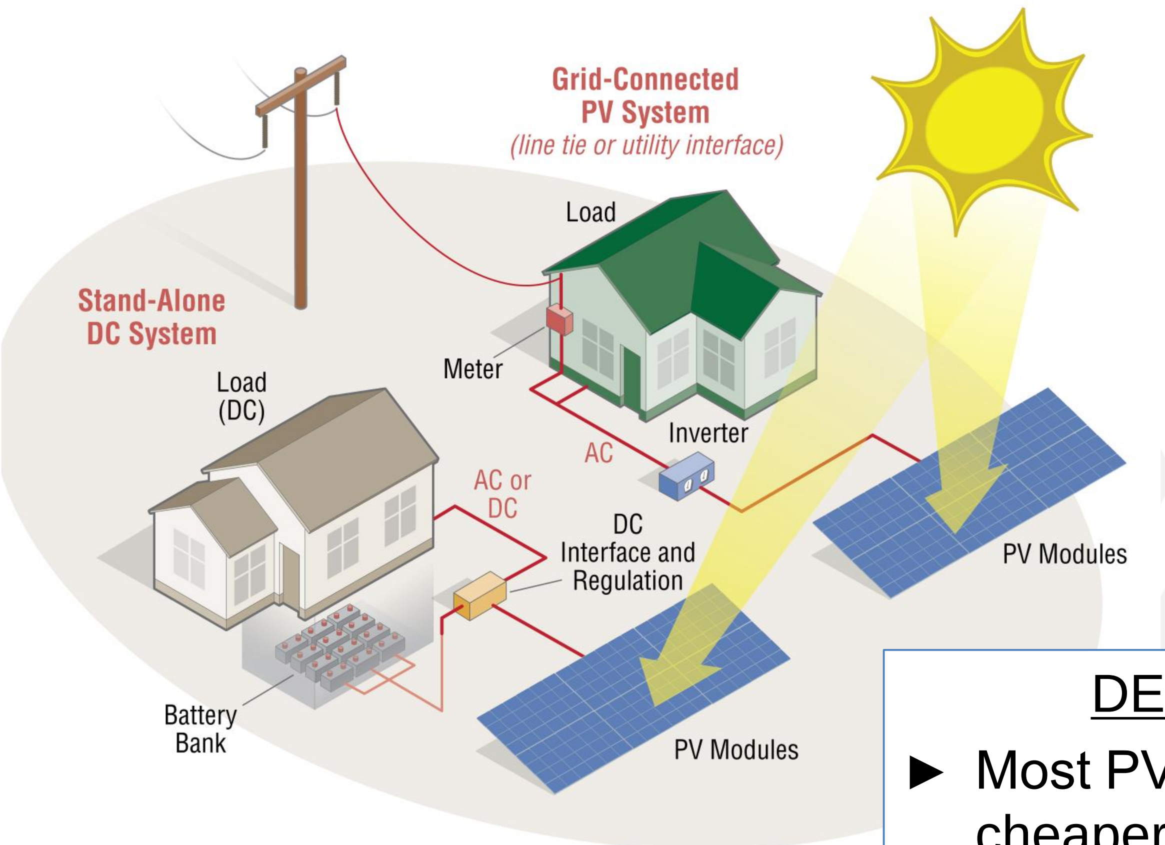
- Converts direct current (DC) from photovoltaic modules to alternating current (AC) to match the utility grid
- Implements Maximum Power Point Tracking (MPPT)

DER Characteristics

- Provides energy from the sun
- Only produces energy when sun is shining (cold is better)
- Non-dispatchable, and may export to grid if greater than load



Grid Tie and Stand-Alone PV/Battery

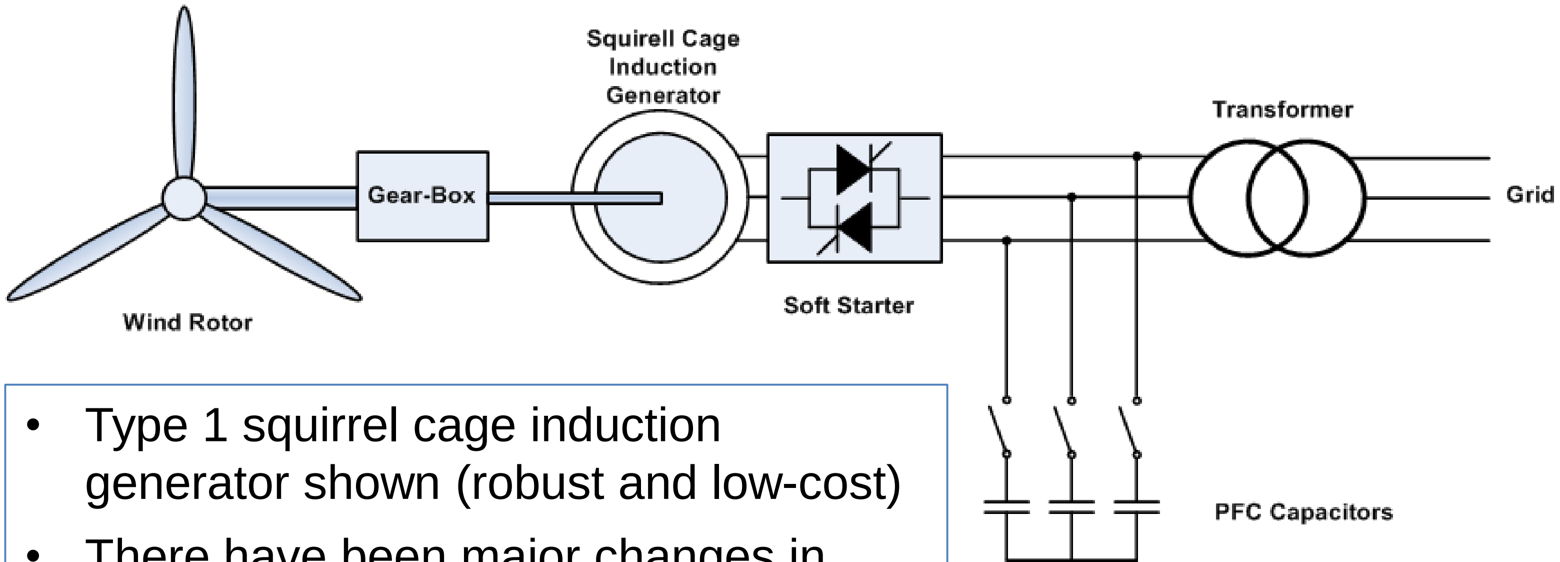


Source: NREL

DER Characteristics

- Most PV today is "grid tied" and cheaper (no batteries required)
- Early PV and remote locations are stand-alone systems with batteries, load limits

Wind Generators
Squirrel-cage Induction Generator



- Type 1 squirrel cage induction generator shown (robust and low-cost)
- There have been major changes in wind technologies over past 20 years
- Most wind machines installed today are large (Type IV), and not tied to distribution grid
- Distributed wind generation are now less common

Source: NREL

DER Characteristics

- ► Provides energy from wind
- ► Only produces when wind blows, so variable
- ► Non-dispatchable, so may export if load is low

Battery Electric Storage Systems (BESS)

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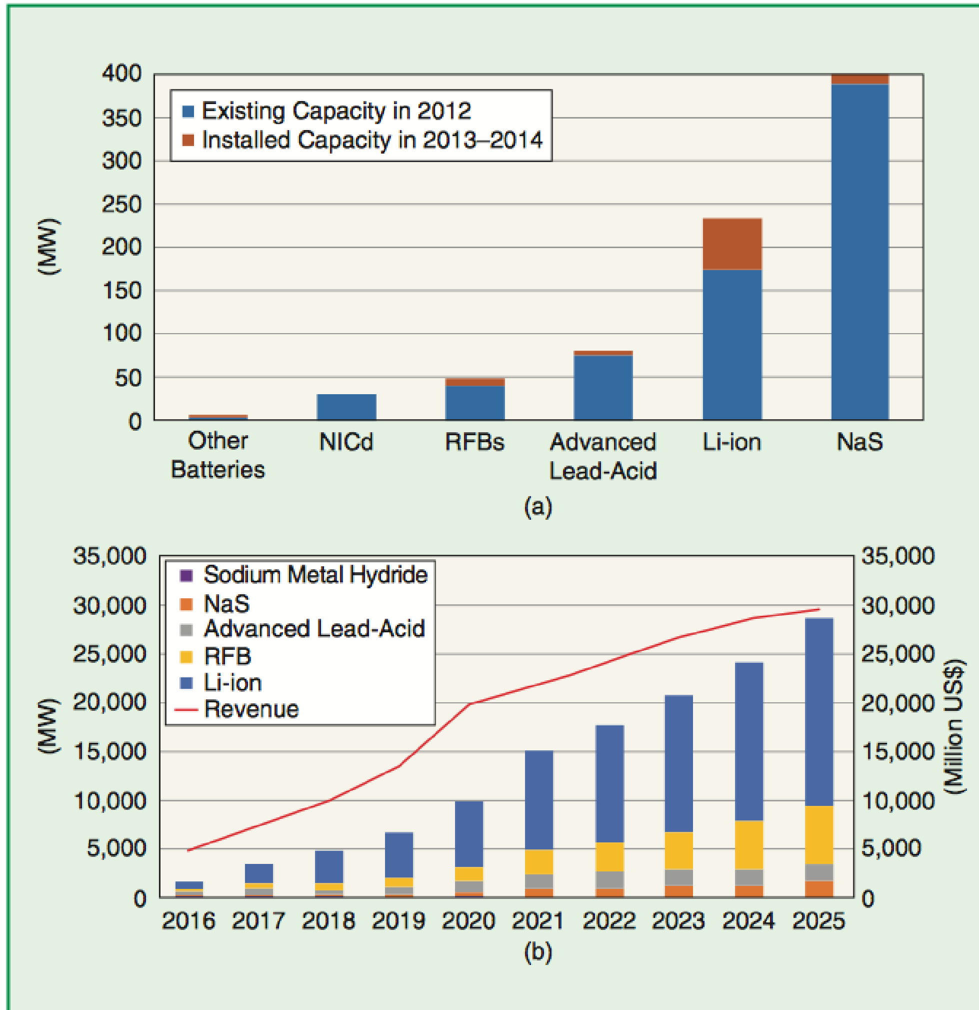
- Lead-Acid Battery
- NiMH Battery
- Li-Ion Batteries
  - LMO
  - LFP
  - LNMC
  - LTO
  - Li-S
- Redox Flow Battery
- Sodium Sulfur Battery

Source: NREL



Estimated installed battery capacity

Source: IEEE P&E September/October 2017

Battery Electric Storage Systems (BESS)

DER Characteristics

- ► Can be both a load and a source of power and energy
- ► May be configured to provide backup power during emergencies
- ► High cost per unit of storage energy
- ► Considered a Key Technology to help stabilize the grid, reduce demand
- ► Potential to eliminate backfeed in conjunction with other DERs - which may negate the need for NEM metering/policies
- ► May be configured to be dispatchable, unlike wind and solar technologies

Smart Buildings with Active EMS

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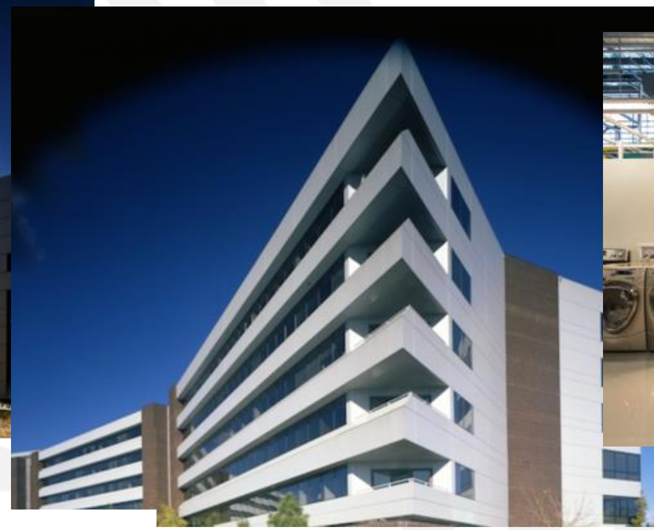


<u>DER Characteristics</u>

- ► Active Energy Management Systems (EMS) are critical to create “smart buildings” that respond to market or utility signals
- ► May utilize Demand Response (DR) systems
- ► Leverage Energy Efficiency (EE) components within building
- ► May leverage generation or computing for heat

Source: NREL Pix

Electric Vehicles (EV or V2G)

Source: NREL Pix

<u>DER Characteristics</u>

- ► Can use clean energy when grid is underutilized (nighttime)
- ► PV may be used to charge EVs during daytime hours
- ► Today EV are only loads, but V2G is a promising technology (BESS)

Micro-Grids

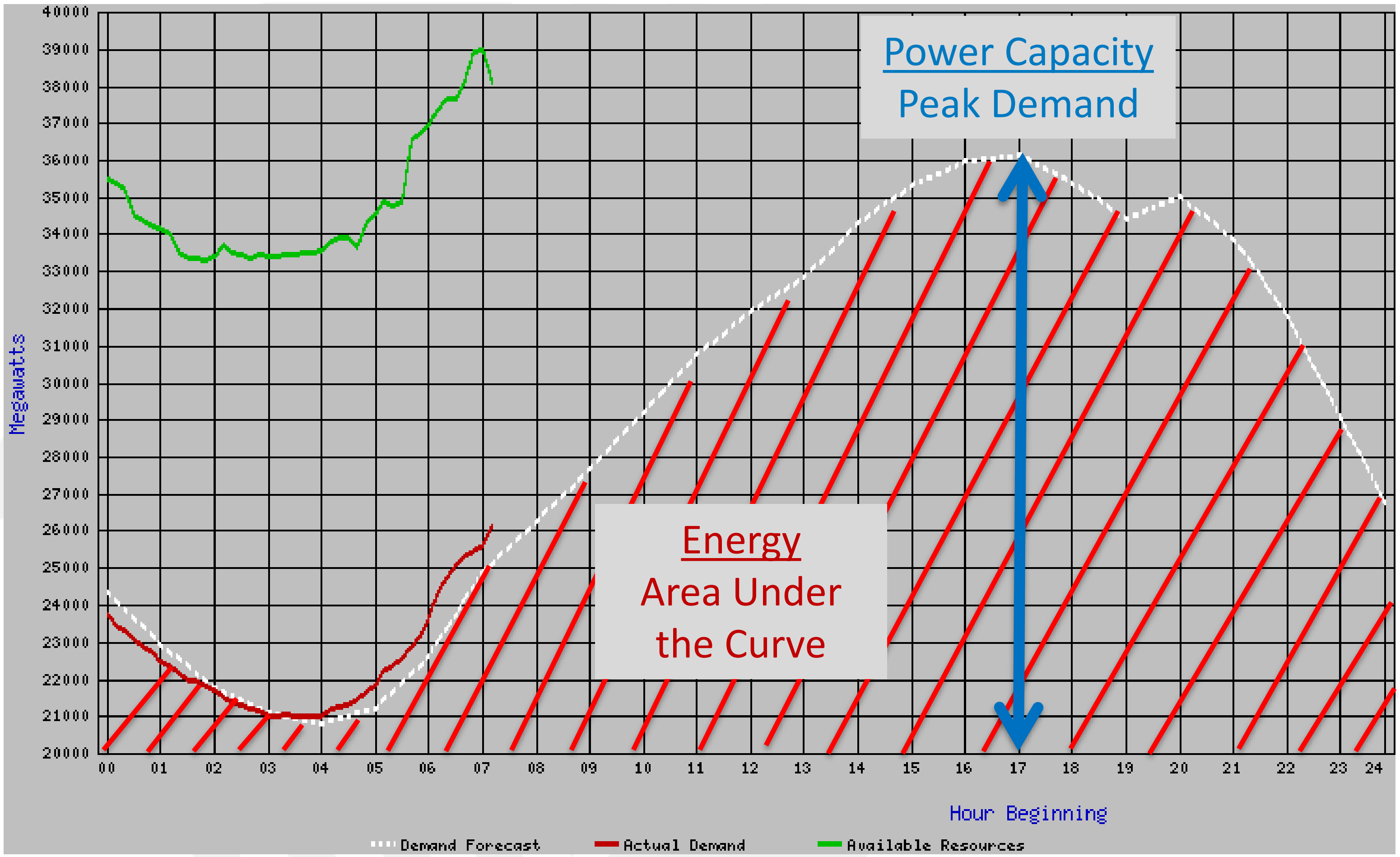
Source: NREL Pix

<u>DER Characteristics</u>

- May combine one or more DER technologies, but must have storage
- Increasingly being used as backup for critical reliability needs
- May stand-alone or be grid-tied
- Controls in infancy today

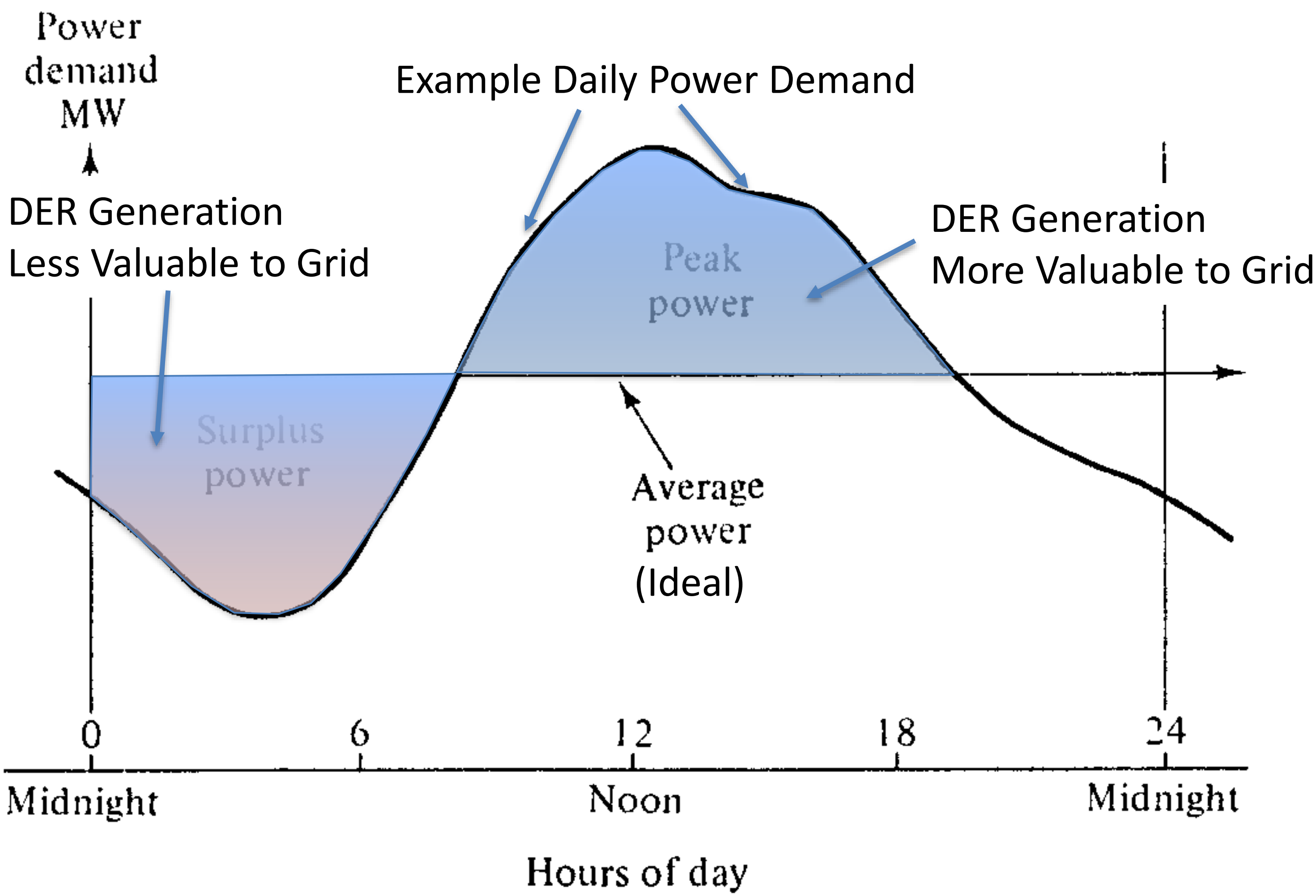
Providing Power & Energy to the Grid (and other functions & support)

Power (MW) vs. Energy (MWh)



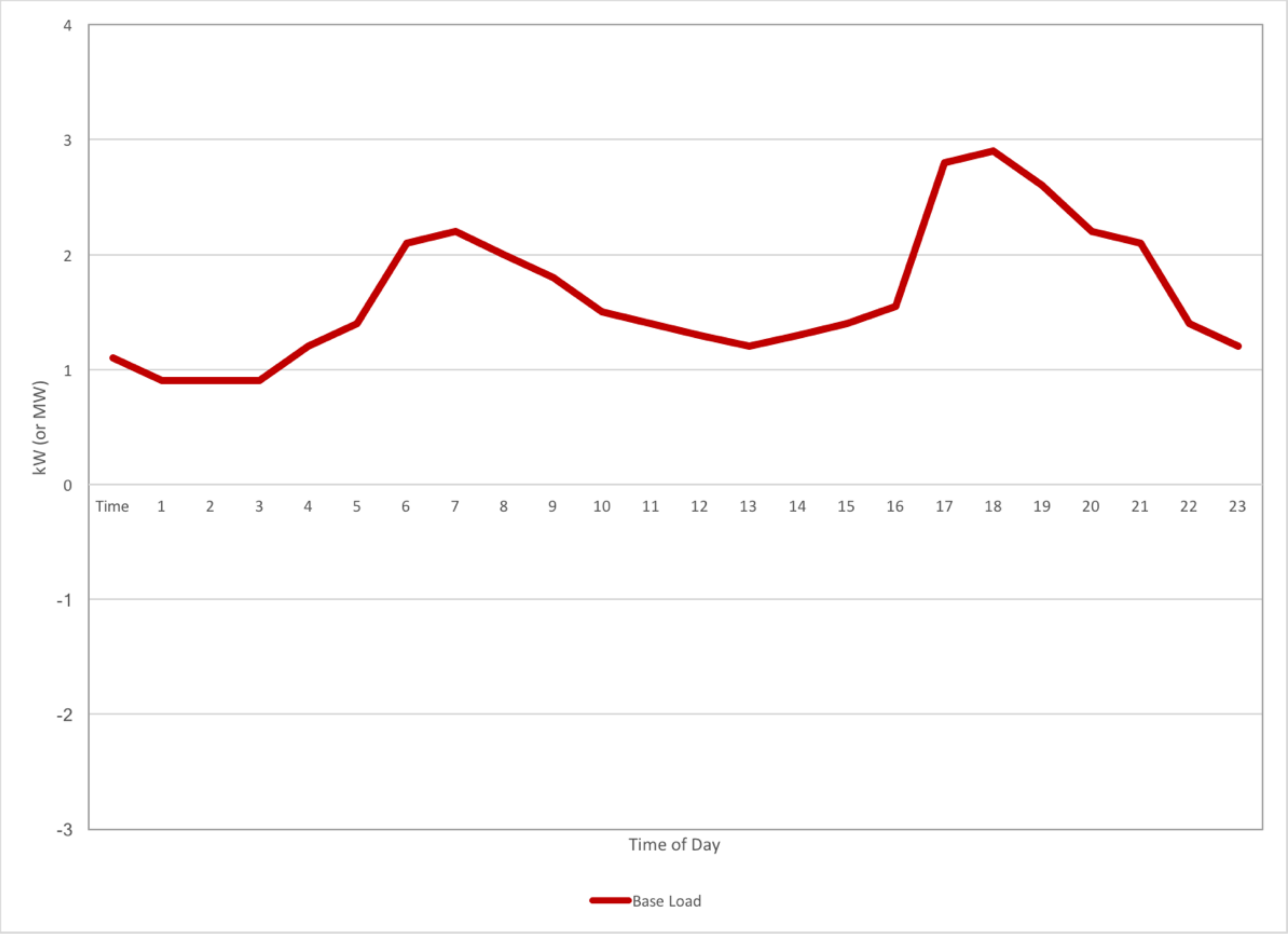
Reference: California ISO (www.caiso.com/outlook)

DER Supporting Power and Energy Needs



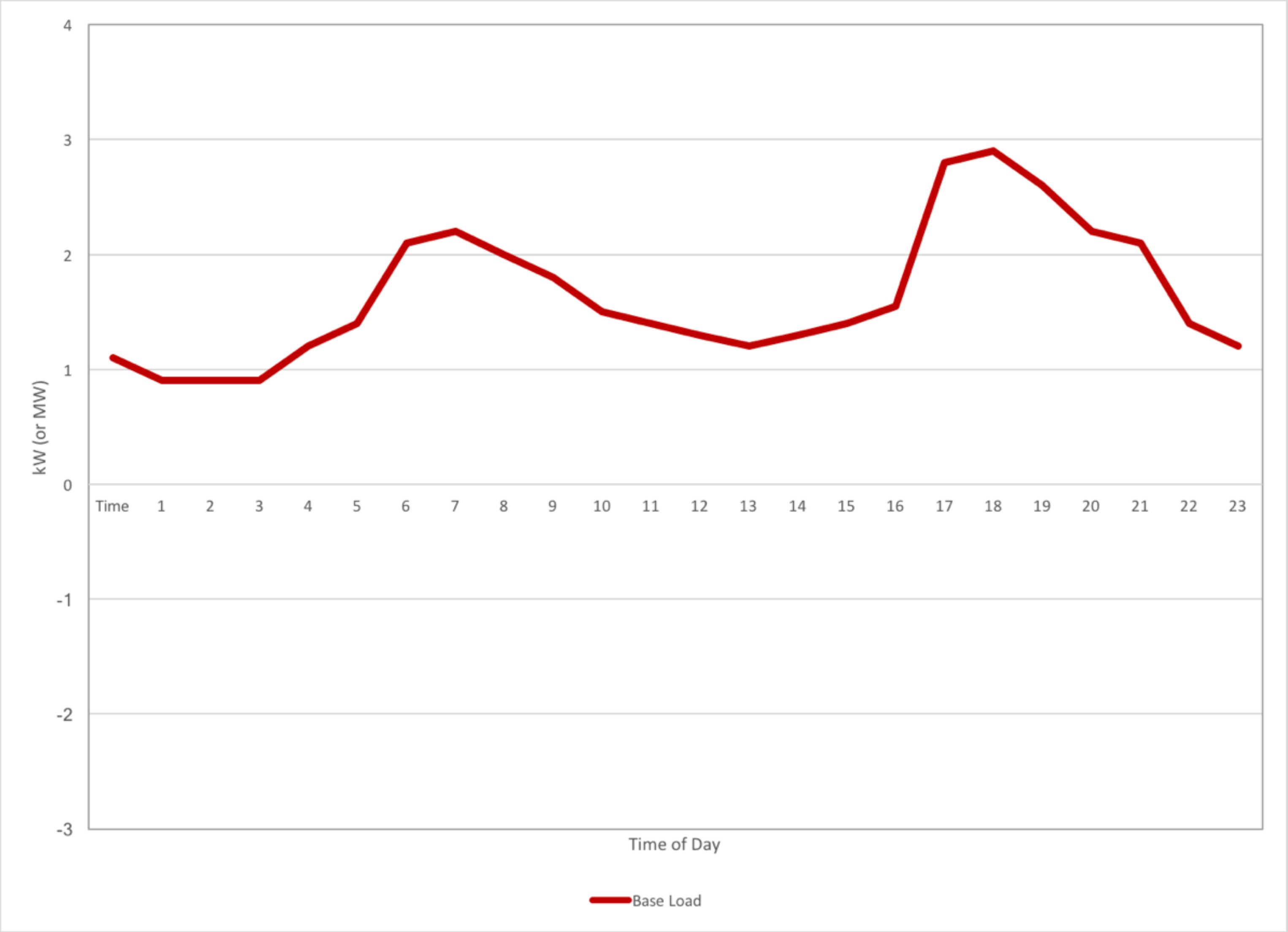
Source: Ravel Ammerman

Examples of Load, Generation, Storage, etc.



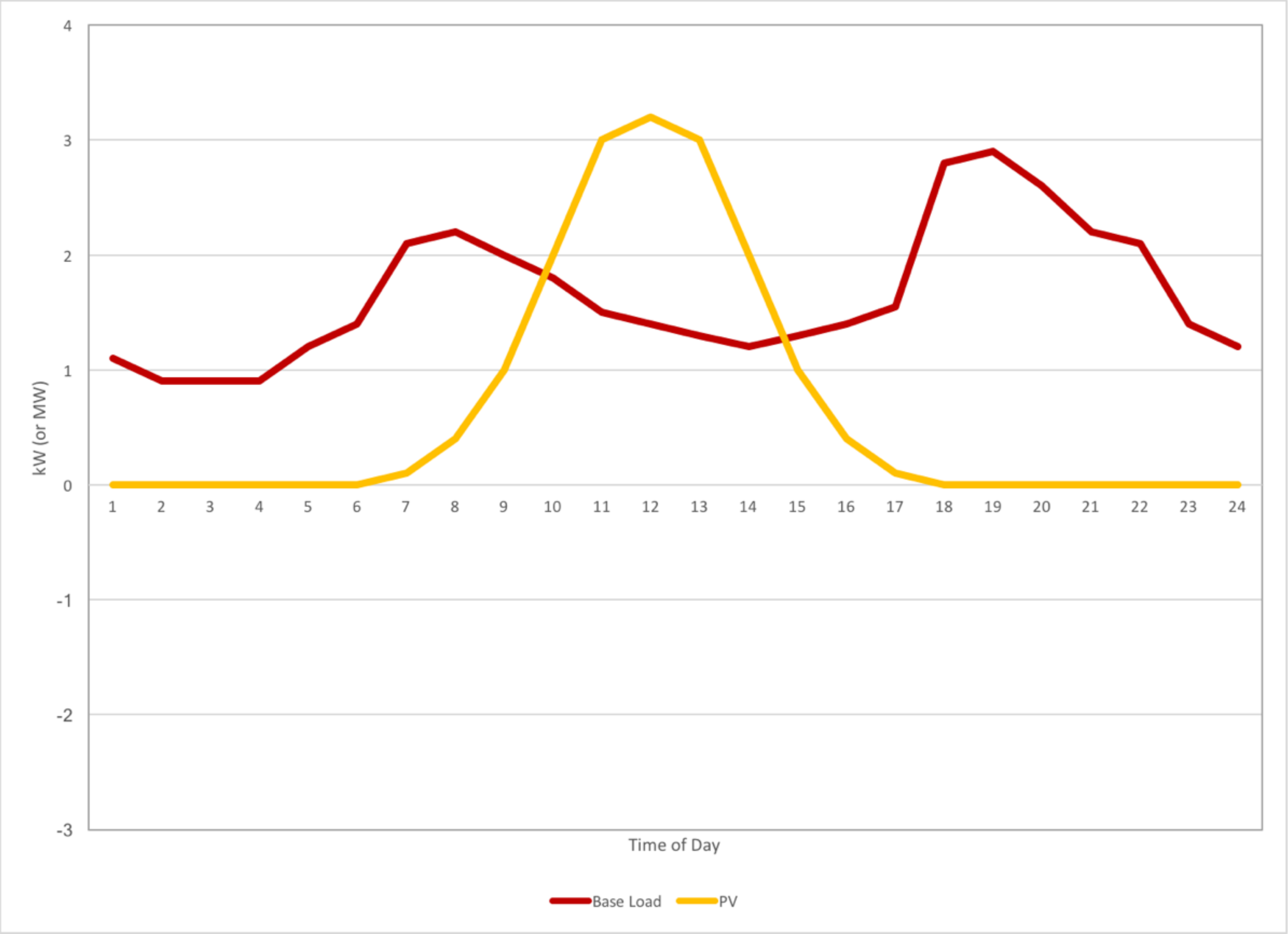
Source: NREL

Example Load Profile



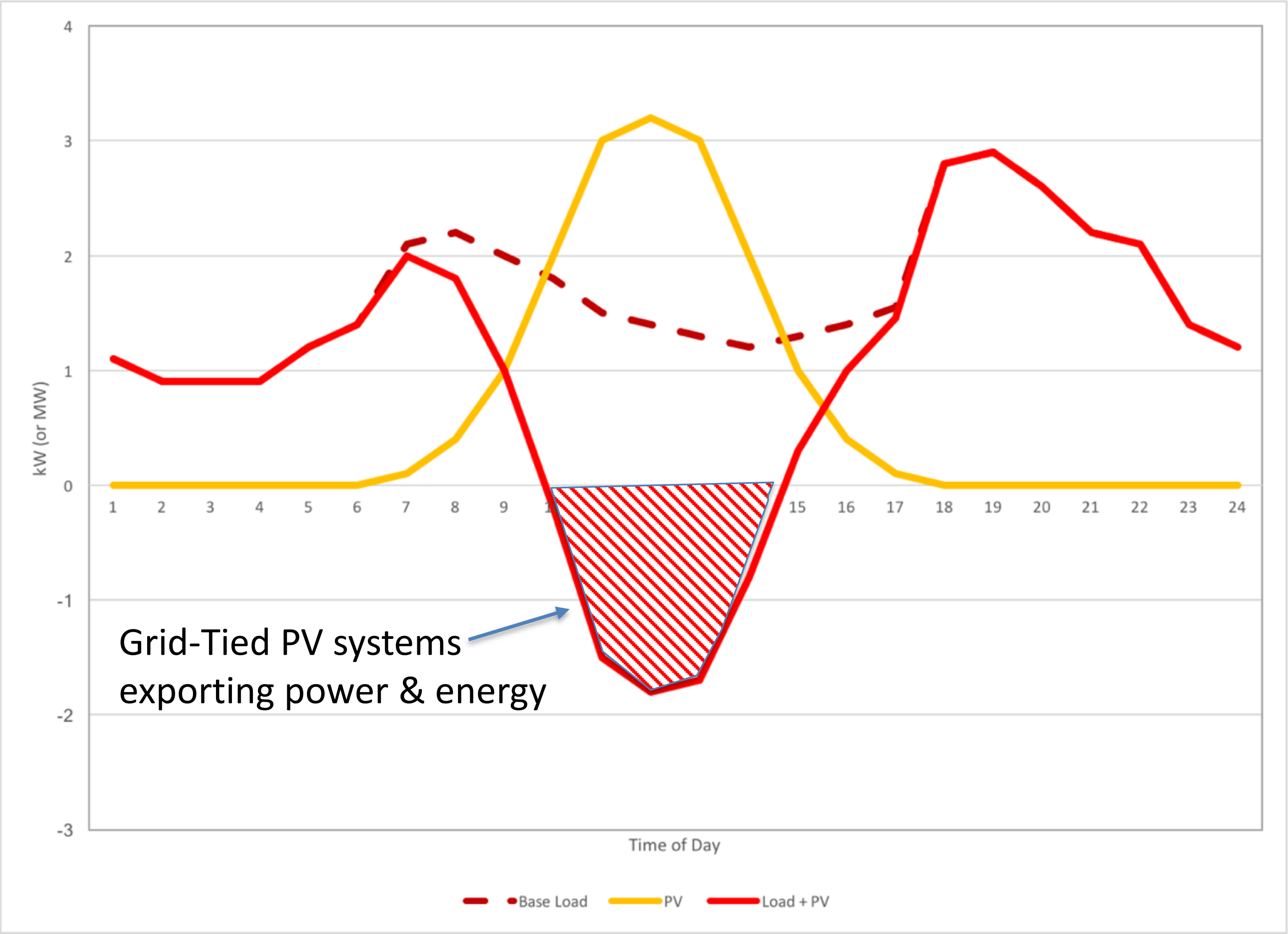
Source: NREL

Examples of Load and PV



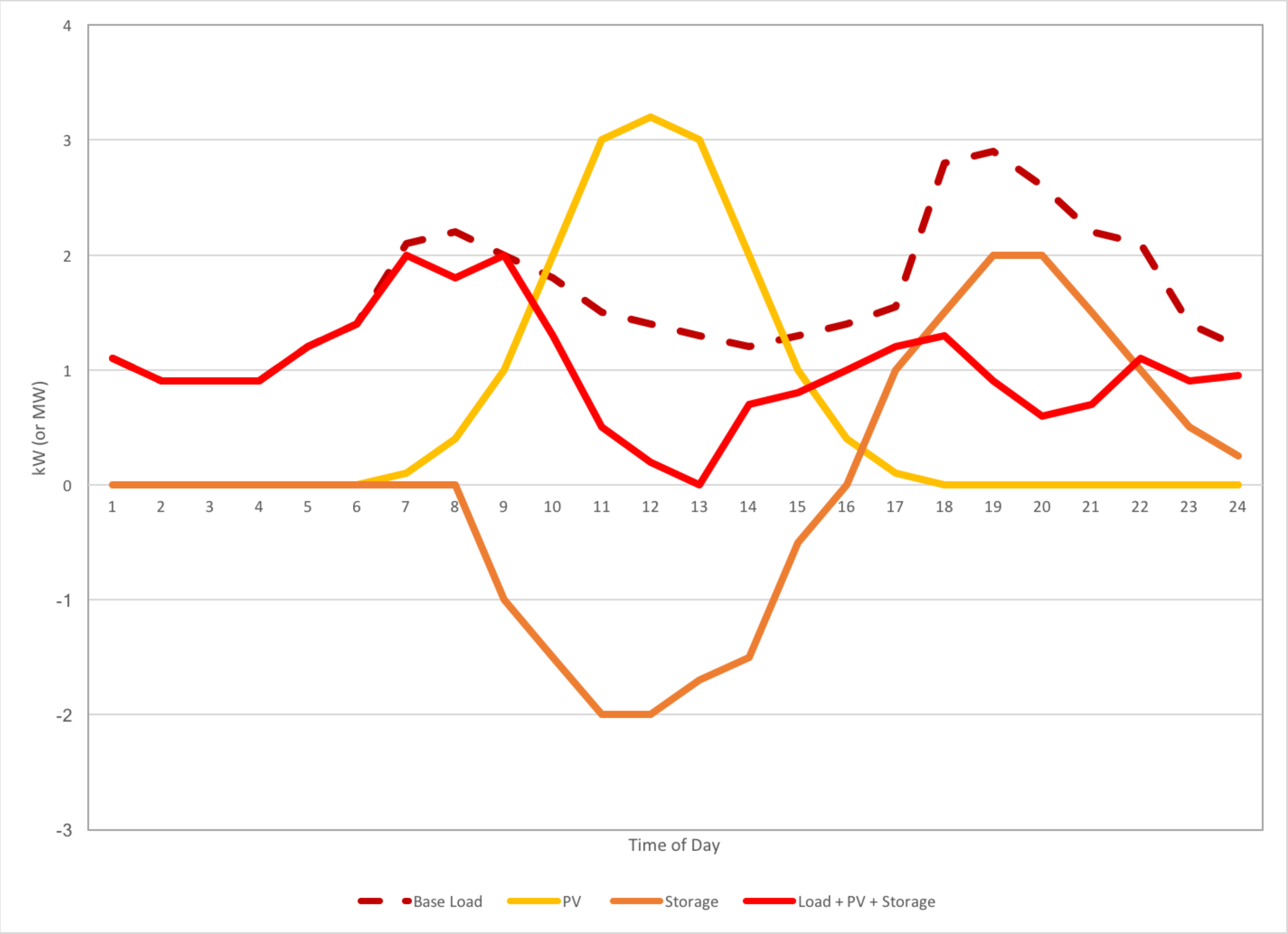
Source: NREL

Examples of Load and PV



Source: NREL

Examples of Load, PV & Batteries



Source: NREL

Penetration of DERs – Important Distinctions

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- Capacity Penetration = total nameplate capacity of all distributed resources on the feeder (or line section) divided by peak annual load on feeder (traditional)
  - Normally calculated as capacity of installed PV generation/peak non coincident feeder load
  - Other ways it is calculated is as a function of the minimum non coincident day time load
  - Generally used for technical studies/evaluations/limits/maps
- Energy Penetration = Total energy produced by all DERs on a feeder or utility territory divided by total energy consumed on a feeder or utility territory
  - Mostly used for policy discussions as in Renewable Portfolio Standards

Utility Concerns Regarding DER Impacts on Distribution & Operations

Question: How much DER can a Feeder Host?
Answer: It Depends….

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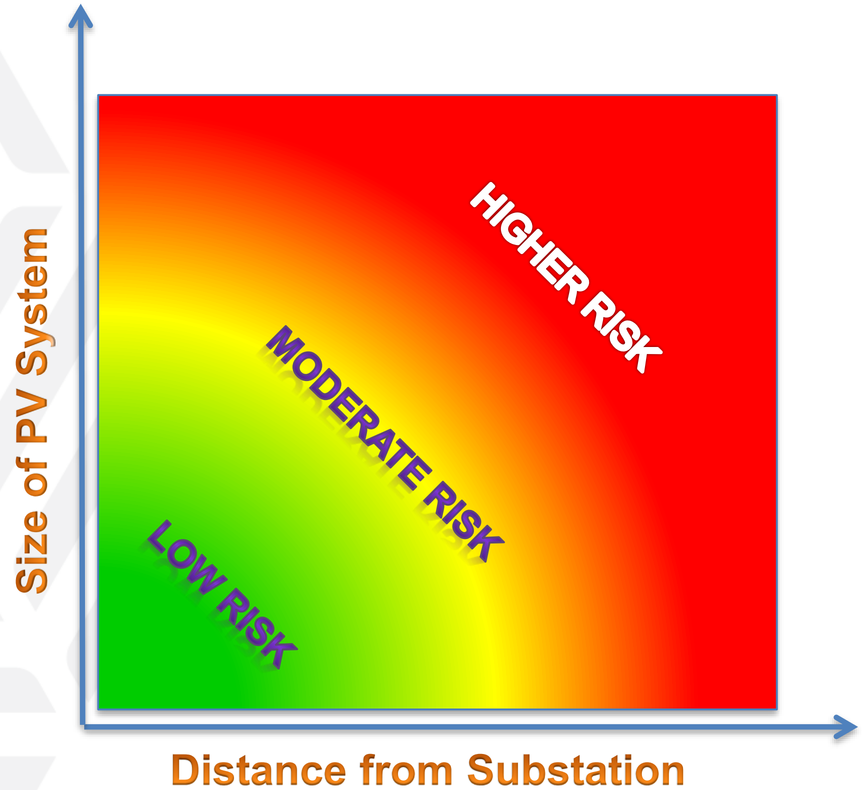
There are many variables……

- Grid Hosting Capacity (GHC) depends on location, but is the maximum size DER that can be installed anywhere on a circuit without electrical upgrades/changes. So a feeder can have a GHC, but a "Locational GHC" is more specific
- The absolute **maximum** limit will depend on the thermal limits of the conductors, circuit breakers, fuses, switches, and traditional electric design criteria
- The GHC can be changed once updates are completed or smart inverters deployed, and varies

Factors Determining Hosting Potential

- ► Size of each PV/DER system
- ► Location of each DER system
- ► Impedance of feeder
- ► Voltage level of distribution system
- ► Size & impedance of substation transformer
- ► Location of capacitor banks
- ► Line regulation configuration
- ► Presence of other DG, Loads
- ► Advanced inverter deployment



Graphic: Michael Coddington, NREL

Utility Concerns on High PV Penetration

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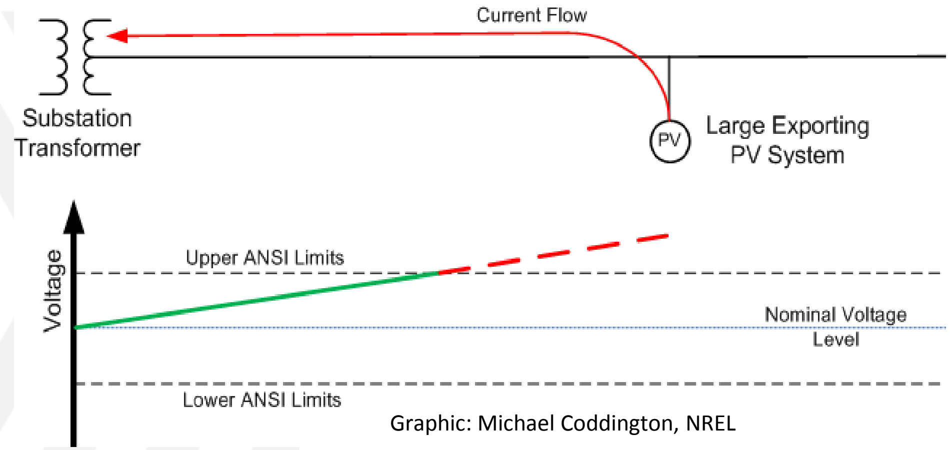
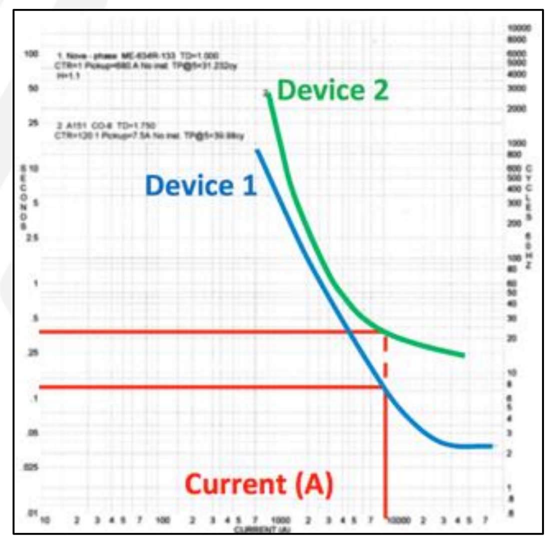
Identified Issues	Relative Priority	Identified Issues	Relative Priority
Voltage Control	High	Equipment Specs	High
Protection	High	Interconnection Handbook	Medium
System Operations	High	Rule 21 and WDAT	Medium
Power Quality	High	IEEE 1547/ UL 1741	Medium
Monitoring and Control	Medium	Application Review	High
Feeder Loading Criteria	High	Clarification of Responsibilities	High
Transmission Impact	Medium	Integration with Tariffs	Medium
Feeder Design	Medium	Coordination with Other Initiatives	Medium
Planning Models	Medium	Source: Russ Neal, SCE	

Significant Grid Impact Concerns

- **Voltage Regulation**
- **Protection coordination (fuses, circuit breakers, relays)**
- **Reverse power flow**
- Increased duty of line regulation equipment
- Unintentional islanding
- Secondary network reliability
- Variability due to clouds
- Capacitor switching
- System **Inertia** for stability MUST be maintained

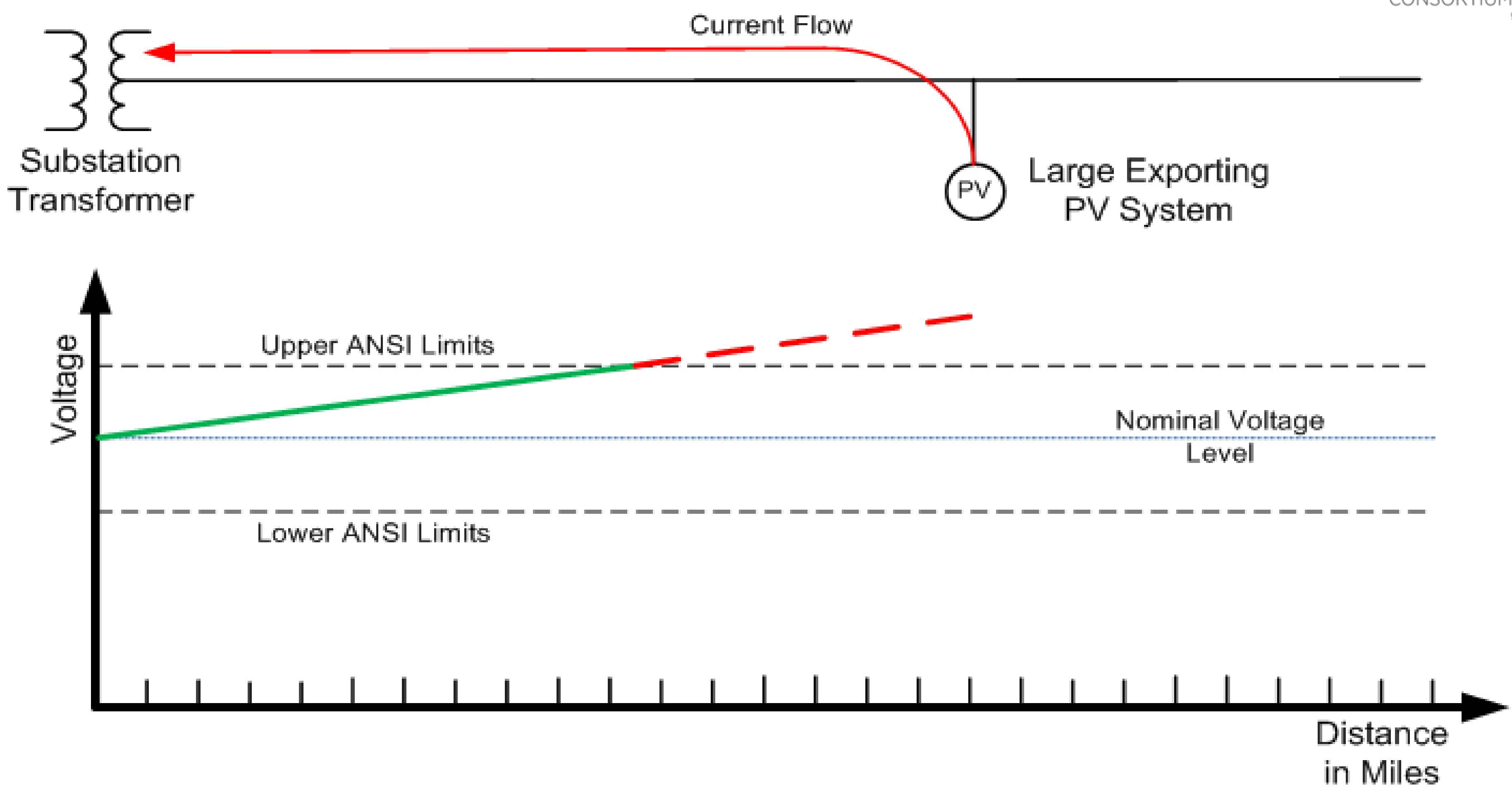


Graphic: Michael Coddington, NREL



Based on interviews with 21 US electric utilities – 2013 – NREL & EPRI (report available)

Common Challenges
Distribution System Voltage Profile – Large PV



Graphic: Michael Coddington, NREL

Common Challenges
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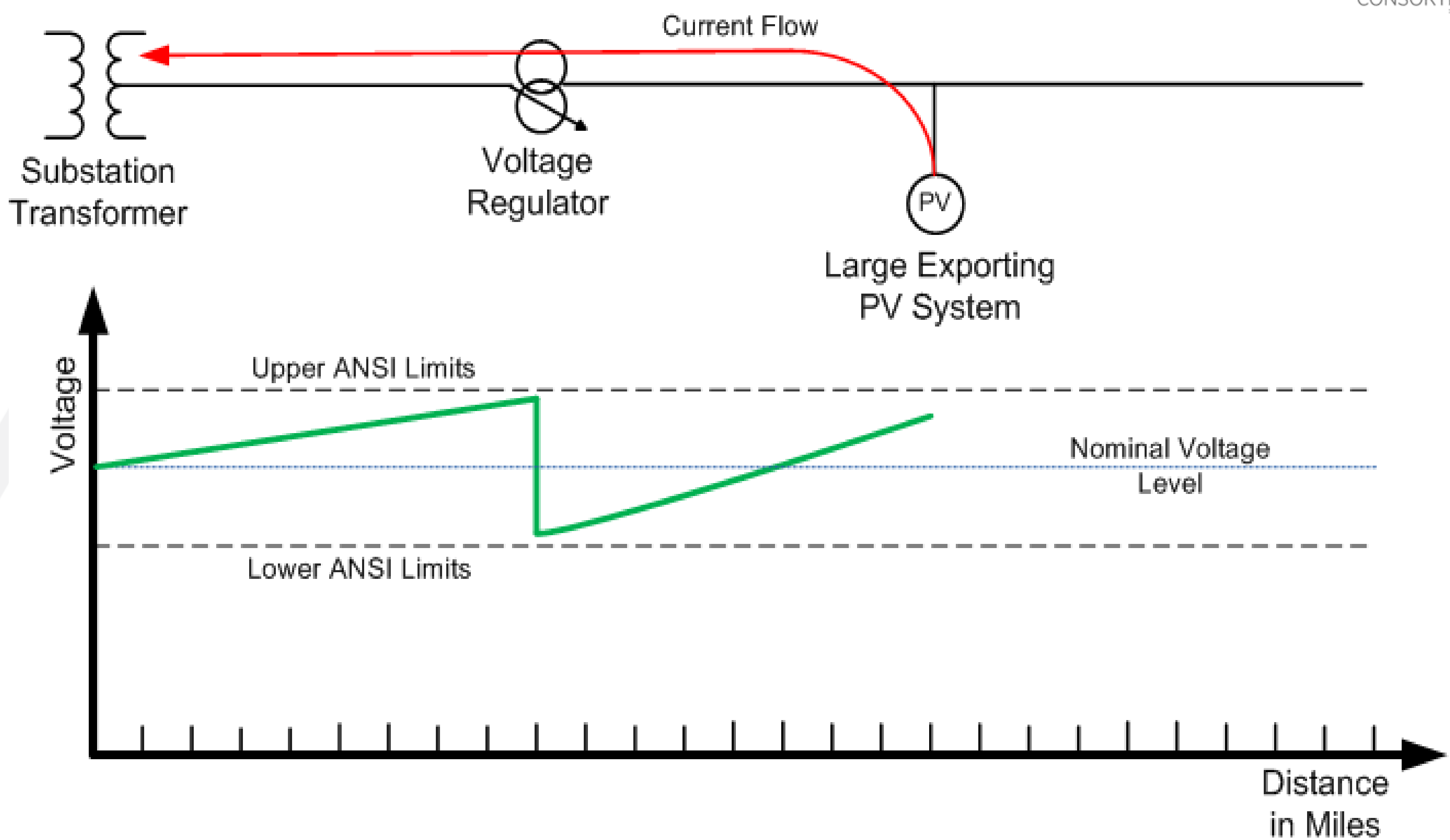
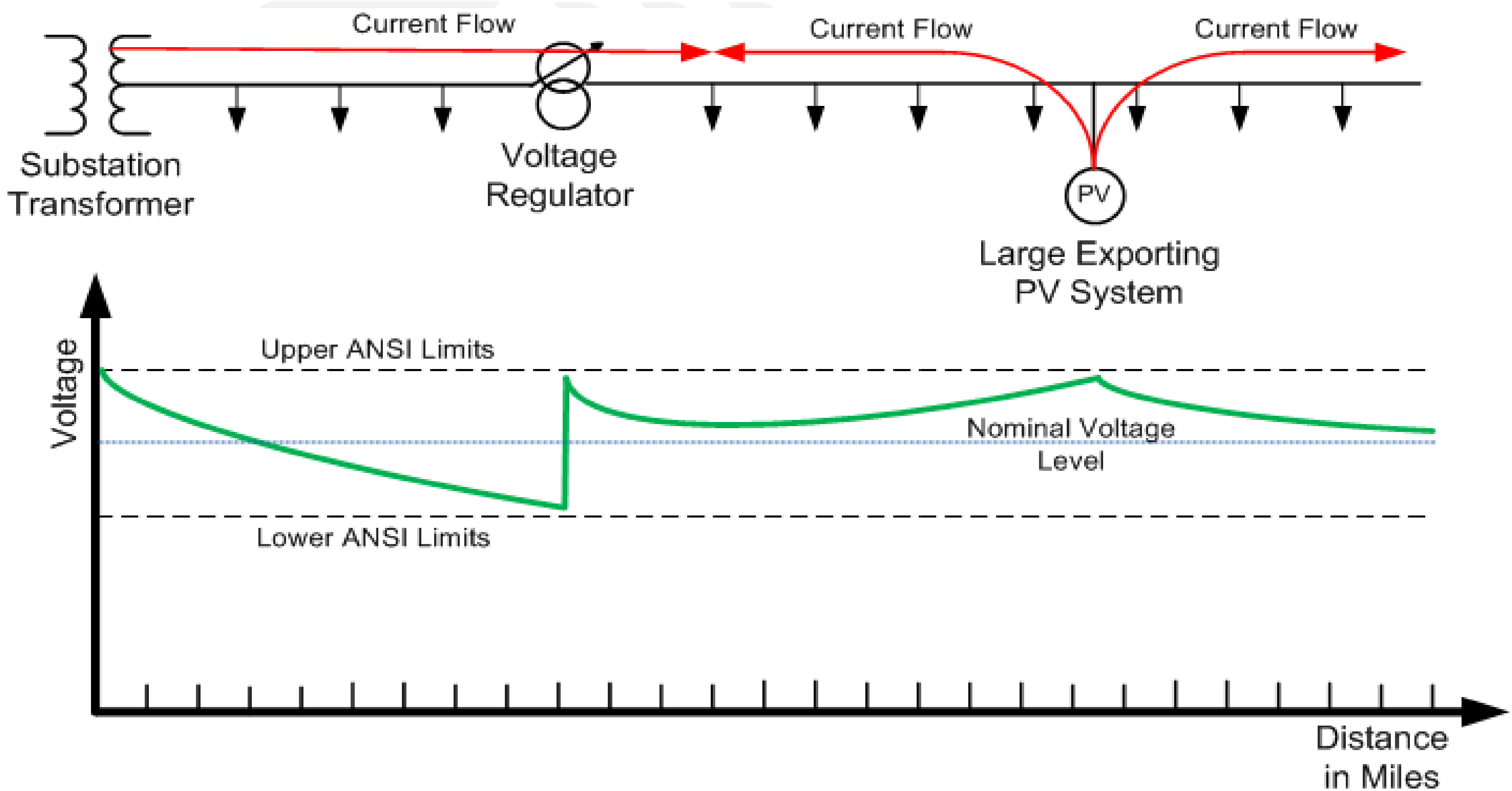


Graphic: Michael Coddington, NREL

Distribution System Voltage Profile – Large PV with localized load (near PV)



Graphic: Michael Coddington, NREL

What Needs to be Mitigated?

Mitigating potentially negative grid impacts

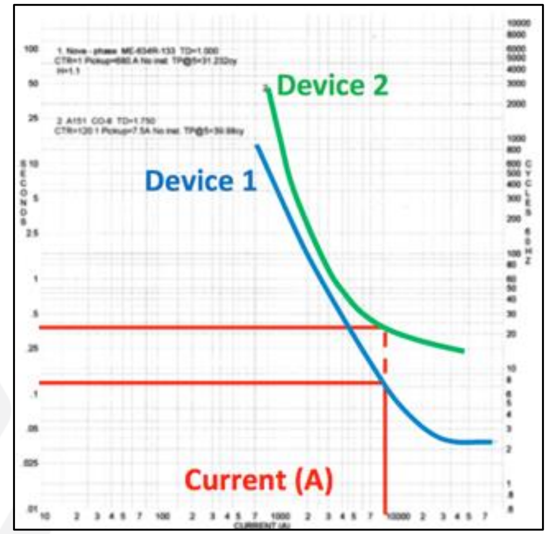
- ► Voltage support / ANCI C84.1
- ► Protection coordination
- ► Reverse power flow (e.g. secondary networks)
- ► Unintentional Island conditions
- ► Flicker effects from cloud variability
- ► Capacitor or voltage regulator switching

Mitigation may be a technical solution, program limit, approved approach, etc. The goal is to avoid any problems.

Mitigation Strategy “Toolbox”

Mitigation Strategy Options
Protection Coordination Mods $
Upgraded Line Sections $--$$$
Voltage Regulation Devices $-$$
Direct Transfer Trip $$$
Communication & Control $-$$$
Advanced Inverters $
Power Factor Controls $
Grounding Transformers $-$$
Capacitor Control Modifications $-$$
Volt / VAR Controls $-$$$
Upgrade Transformer or Secondary conductors $

$-$$-$$$ Denotes ranges of cost for option



From NREL/EPRI “21 Utility Survey on Interconnection”

Technical Limitations that Impact DER Behavior (and Mitigation Strategies)

Can DER Bring Value to the Grid?

Yes, in some cases, absolutely! There are MANY reports and methods to help you understand potential values.

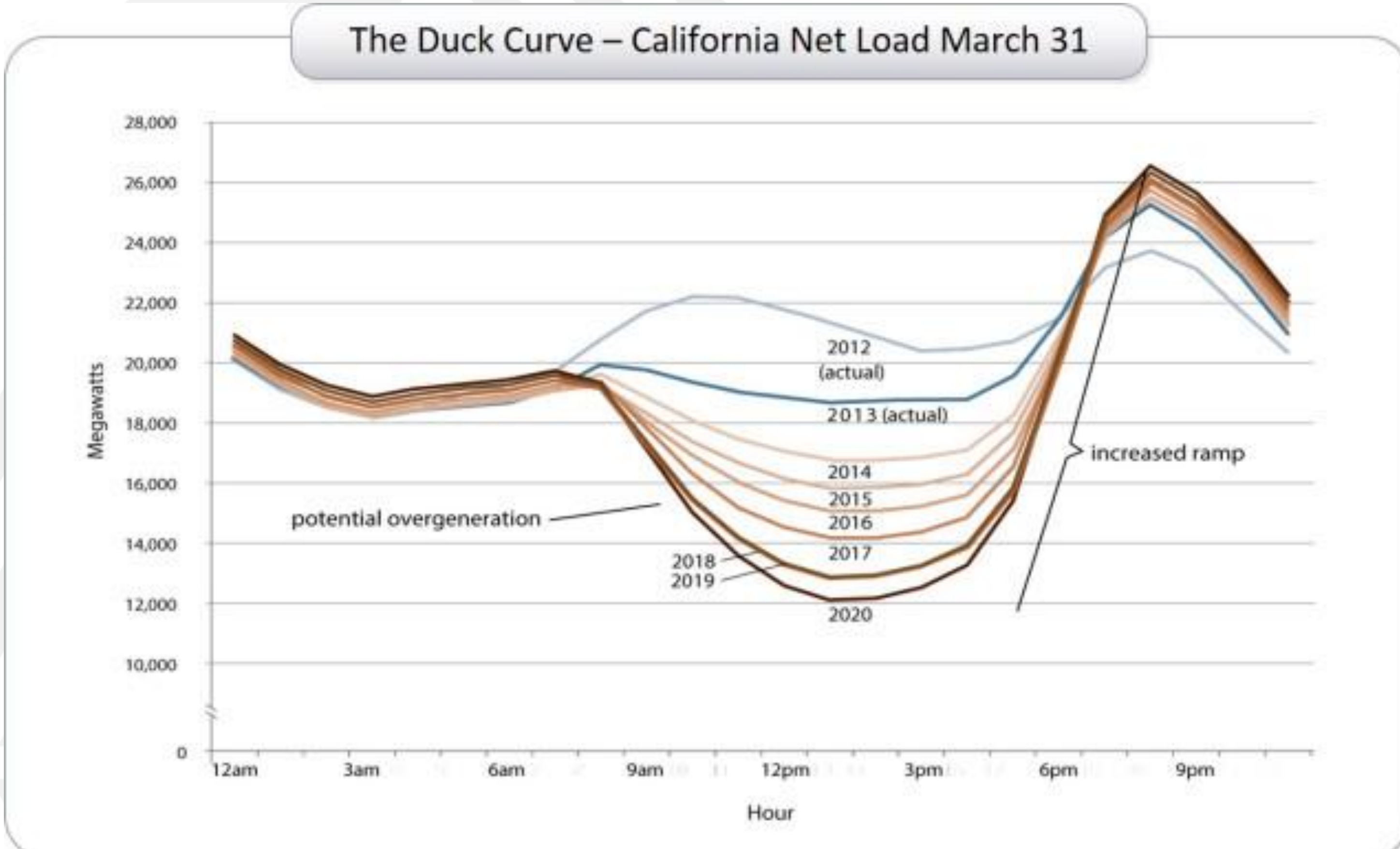
Examples include;

- Deferral of distribution upgrades, substation upgrades, transmission upgrades
- Reduced line losses
- Reduction of emissions near population centers
- Backup power during emergencies
- Time-of-use bill management
- Demand charge reduction
- Energy arbitrage
- Voltage support
- Frequency support
- Increased PV self-consumption (using BESS)
- Spinning/non-spinning reserves
- Black start support
- Etc.

Emma Stewart

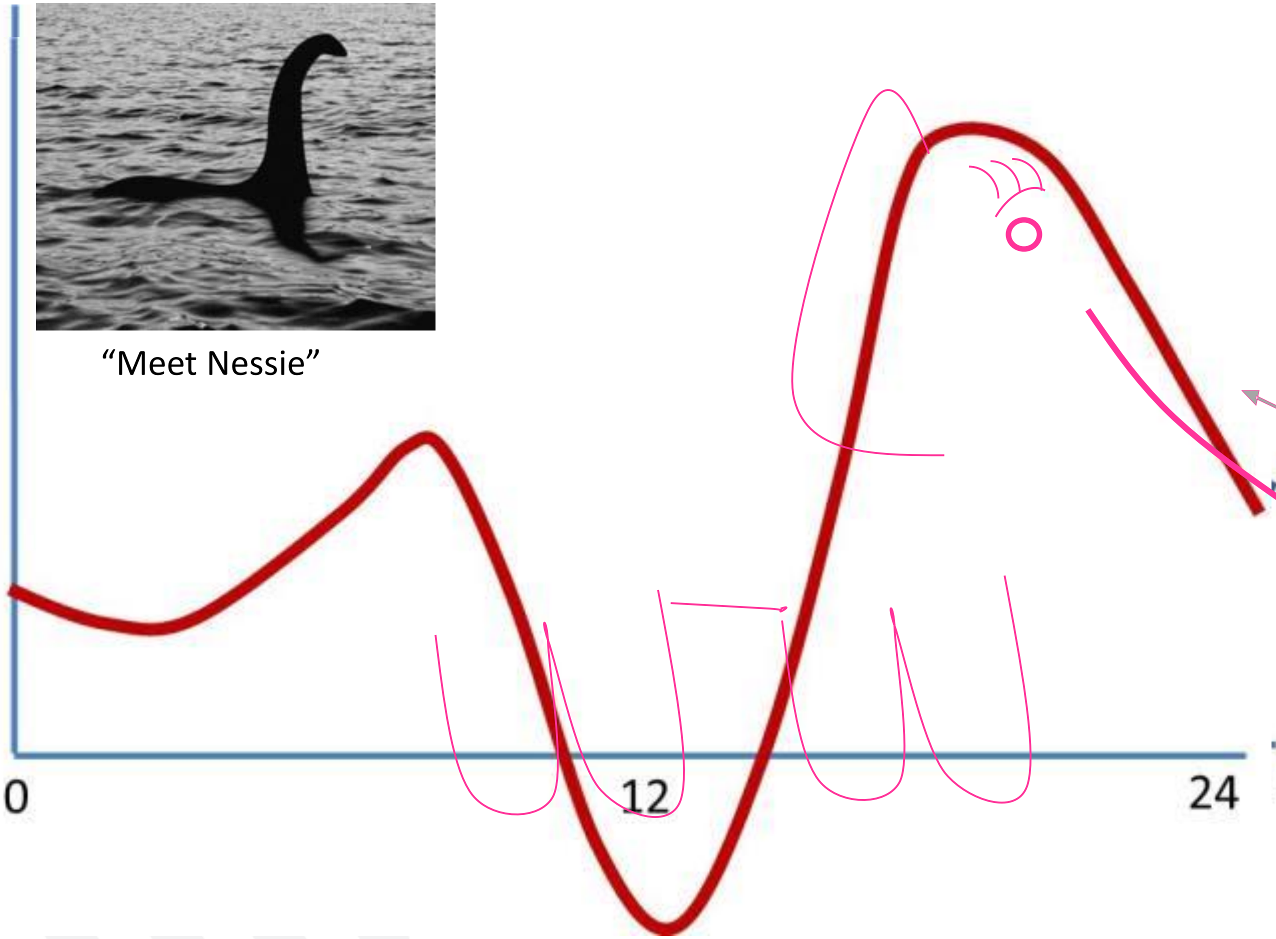
Understanding Intermittency

California Duck Curve



Source: CAISO

Hawaii – the Nessie Curve



"Meet Nessie"

Typical Hawaii load profile – Evening Peaking

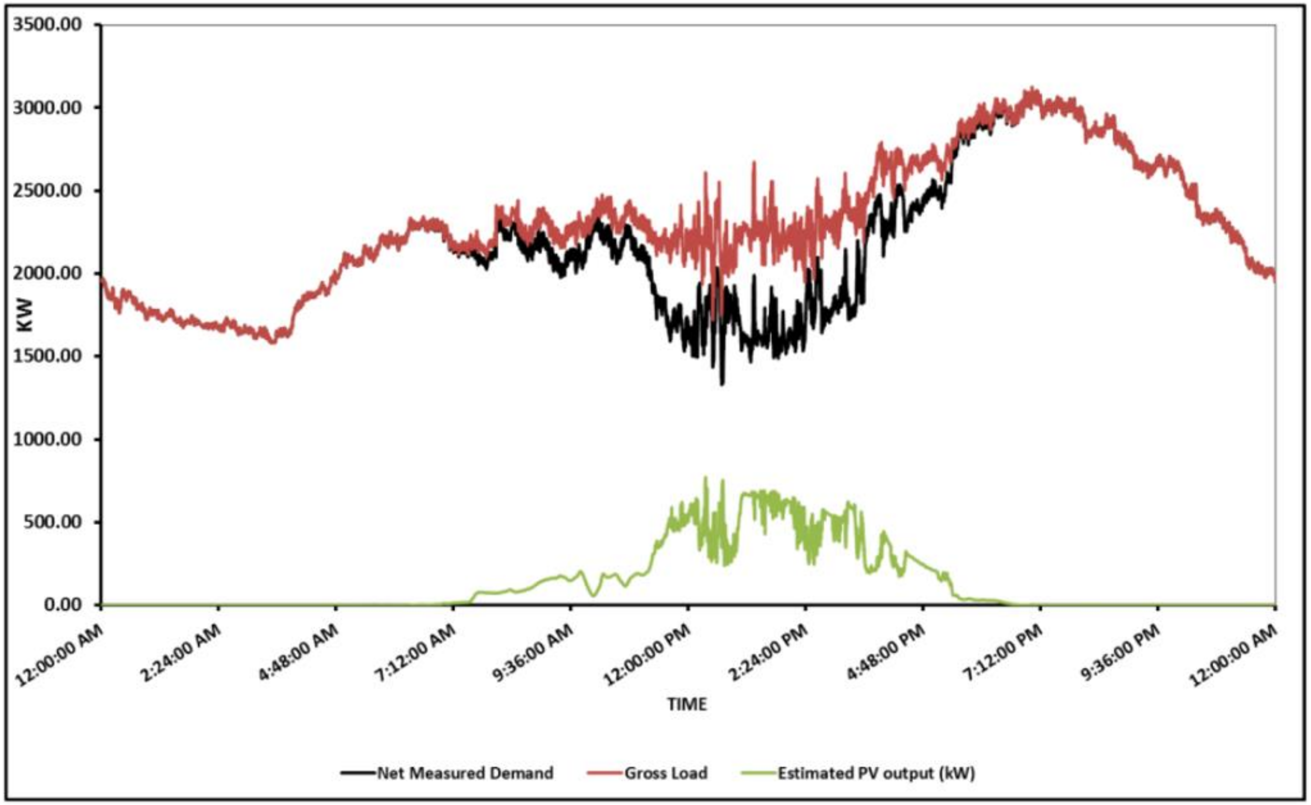
"Bessie the Elephant"

Courtesy of Dora Nakafuji, HECO

What's Our New State?

39

Distribution feeder peaks are often not coincident…dependent on feeder type



Variability Analysis in Hawaii – smoothing with dispersed generation

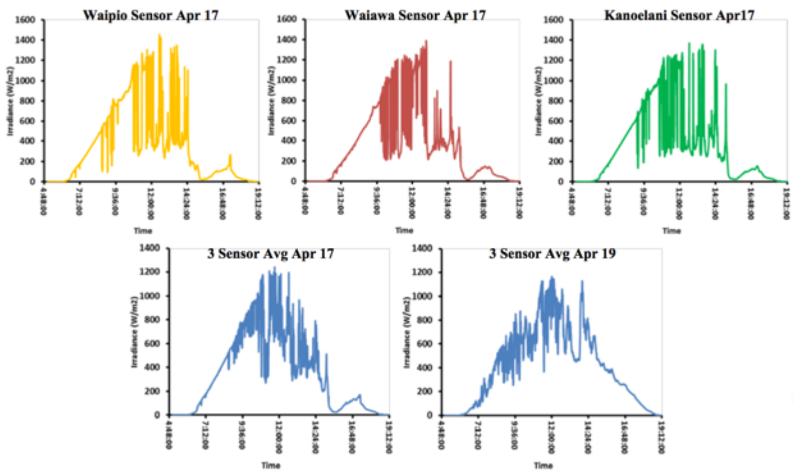
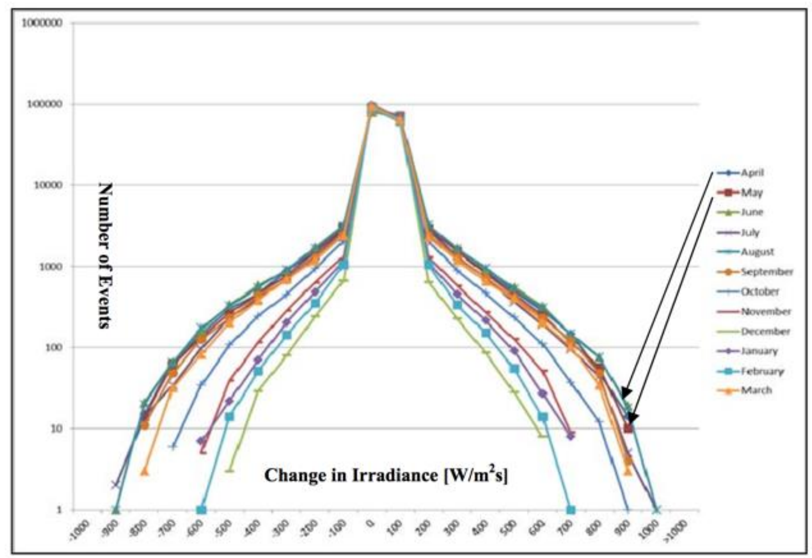


Figure 5: 3 Individual & average irradiance sensor measurements April 17; average irrad

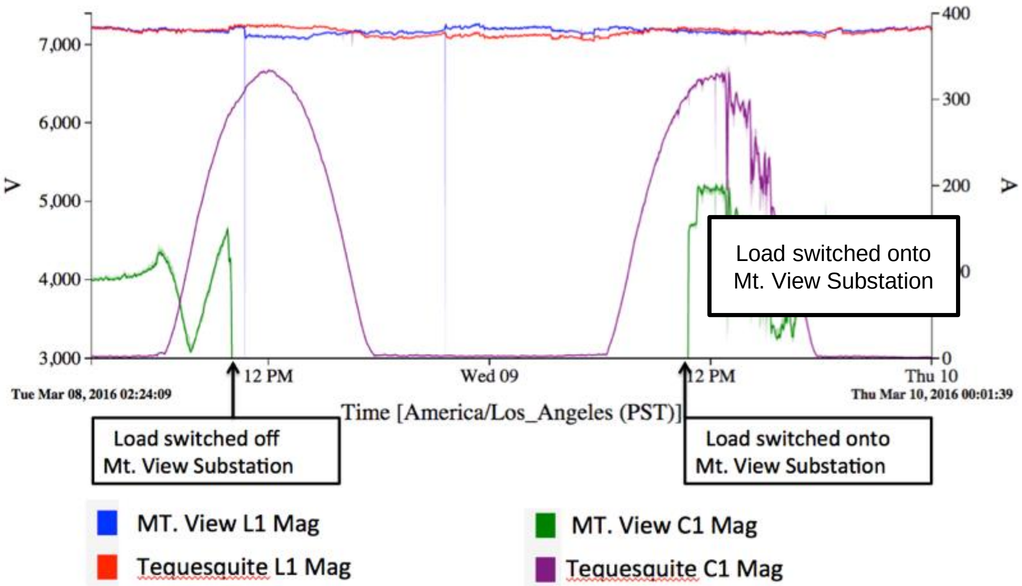
https://www.nrel.gov/docs/fy13osti/54494.pdf

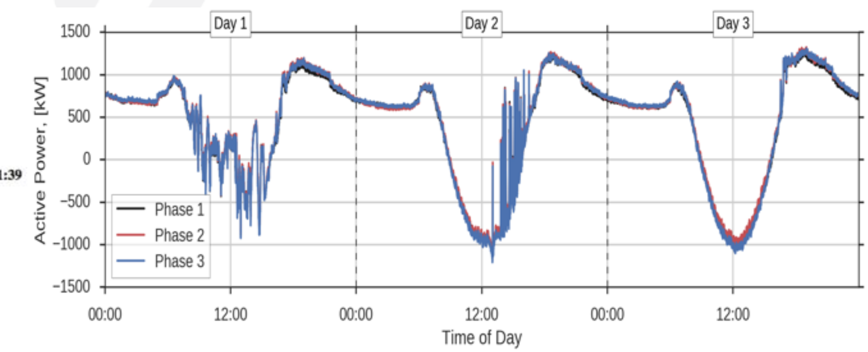


Tracking PV site behavior

- Additional things detected
  - Topology Change Detection & Variability Impact Analysis

- Team Developed State of the PV report
- Daily/weekly report on MwH generated, backfeed hours, max voltage variability, and transients/anomalies





Questions on intermittency – it depends

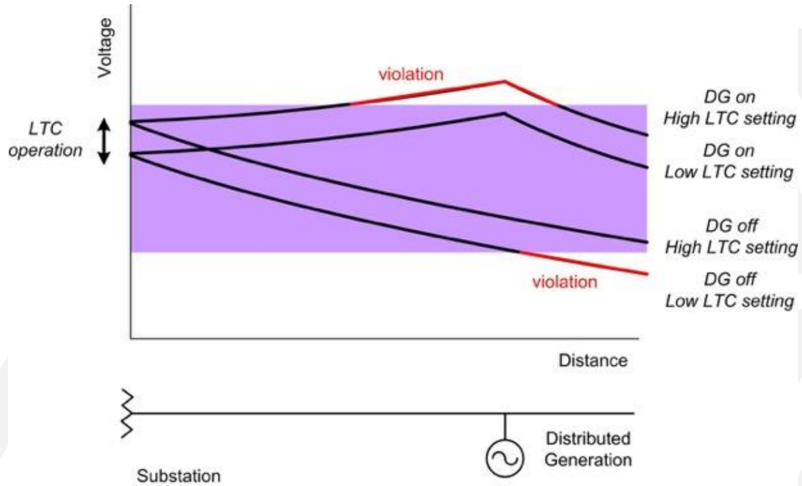
- What happens to load profiles when you combine solar PV with storage? How does storage help you ride out solar PV's intermittency?
  - Depends on the controls
- How can you use storage to reduce a customer's demand and demand charges?
  - Depends on the controls
- What kind of capabilities come with storage products — e.g., fast ramping, island-able?
  - Depends on the product, state and the controls

DG Interconnection Concern: Voltage Regulation and Flicker

- Generators on distribution circuits locally elevate voltage profile while injecting power.
- Their changing operating status increases the range of voltage variation along the circuit (e.g., if suddenly tripping off-line), with potential consequences:
  - may exceed voltage regulation capability on the circuit
  - may cause voltage flicker during lag time before regulator or load tap changer operation, possibly exceeding acceptable level (5%)
  - may cause excessive wear on voltage regulators or load tap changers due to frequent operation

- **Prevention:**
- Careful analysis of voltage profiles and regulation capability

Coordination and control



Coordination Issues

- DG may drive voltage out of range
- DG may wear out legacy equipment “hunting” the voltage
- inverted voltage profile may confuse controls
- voltage status may become even less transparent to operators

DRP's, ICA, and Case Studies

Hosting Capacity and Integrated Analyses

- What is it?
- Why is it different to interconnection?
- Many states making concerted efforts to undertake hosting capacity and integrated resource assessment - examples

What & Why Hosting Capacity: EPRI – Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for NYC

- Definition:
  - Hosting Capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.
- Hosting Capacity is
  - Location dependent
  - Feeder-specific
  - Time-varying

Hosting Capacity can be used to inform utility interconnection processes and to support DG developer understanding of more favorable locations for interconnection

- Hosting capacity considers DER interconnection without allowing
  - Voltage/flicker violations
  - Protection mis-operation
  - Thermal overloads
  - Decreased safety/reliability/power quality
- Hosting capacity evaluations require precise models of entire distribution system

A feeder's hosting capacity is not a single value, but a range of values

Key Components of an Effective Hosting Capacity Method: EPRI – Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for NYC

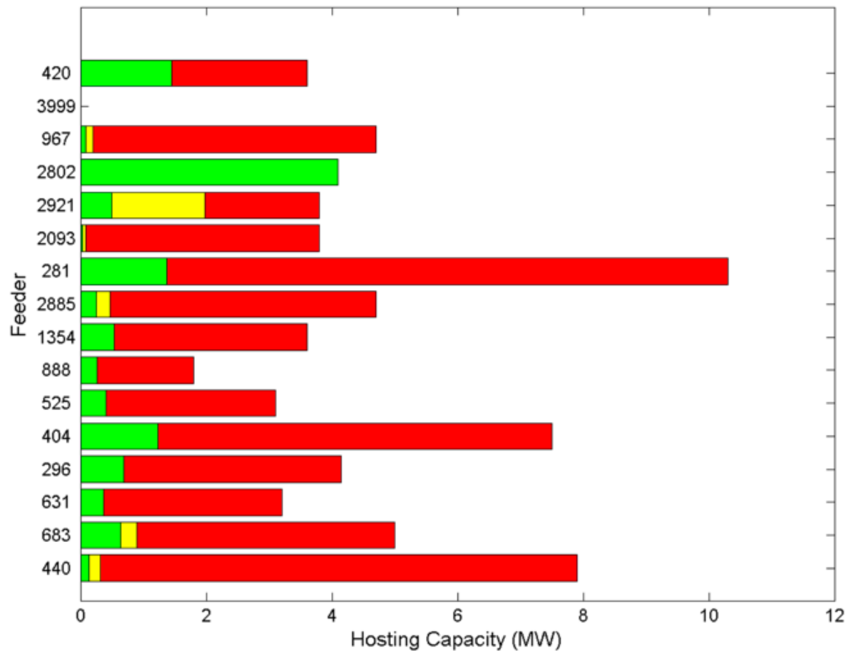
Granular	• Capture unique feeder-specific responses
Repeatable	• As distribution system changes
Scalable	• System-wide assessment
Transparent	• Clear and open methods of analysis
Proven	• Validated techniques
Available	• Using existing planning tools and readily available data

Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for New York State, EPRI, Palo Alto, CA: 2016. 3002008848

Feeder Hosting Capacity and Screening

Feeder Hosting Capacity:
amount of installed PV
(in kW or % of load)
where adverse effects can be ruled out with relative confidence

Problem:
Highly site specific,
requires lots of modeling
but want to have quick, easy rules of thumb



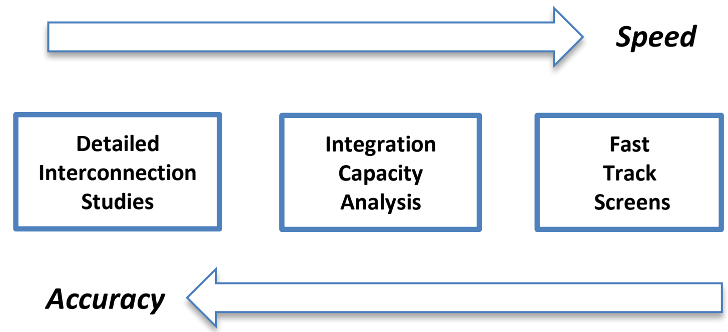
Imperfect Solution:
Apply “Screen” criterion or criteria,
e.g. PV installed capacity < 15% of max feeder load
if YES, then OK
if NO, then perform a detailed, time consuming impact study

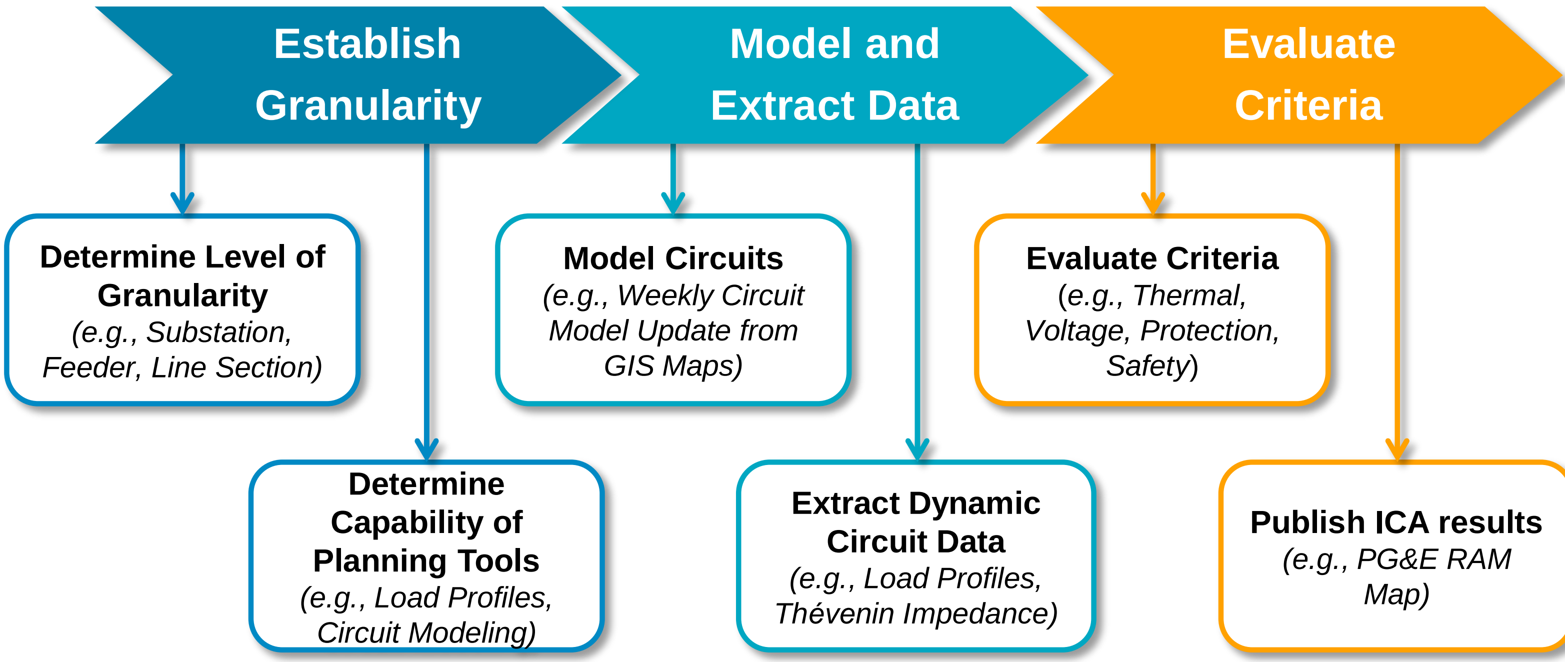
http://calsolarresearch.ca.gov/images/stories/documents/Sol3_funded_proj_docs/EPRI/Modeling-Analysis-16-Feeders_3002005812.pdf

New Methodology to Determine Locational DER Capacity

New methodology was required to be developed to calculate DER Integration Capacity

- PG&E was instructed to develop a new methodology to help determine locational DER capacities that would not require significant upgrades to interconnect
- Methodology considers important criteria and aspects considered in detailed engineering reviews during interconnection
- Result is capacity values that estimate when significant impacts are not expected and detailed review is not necessary

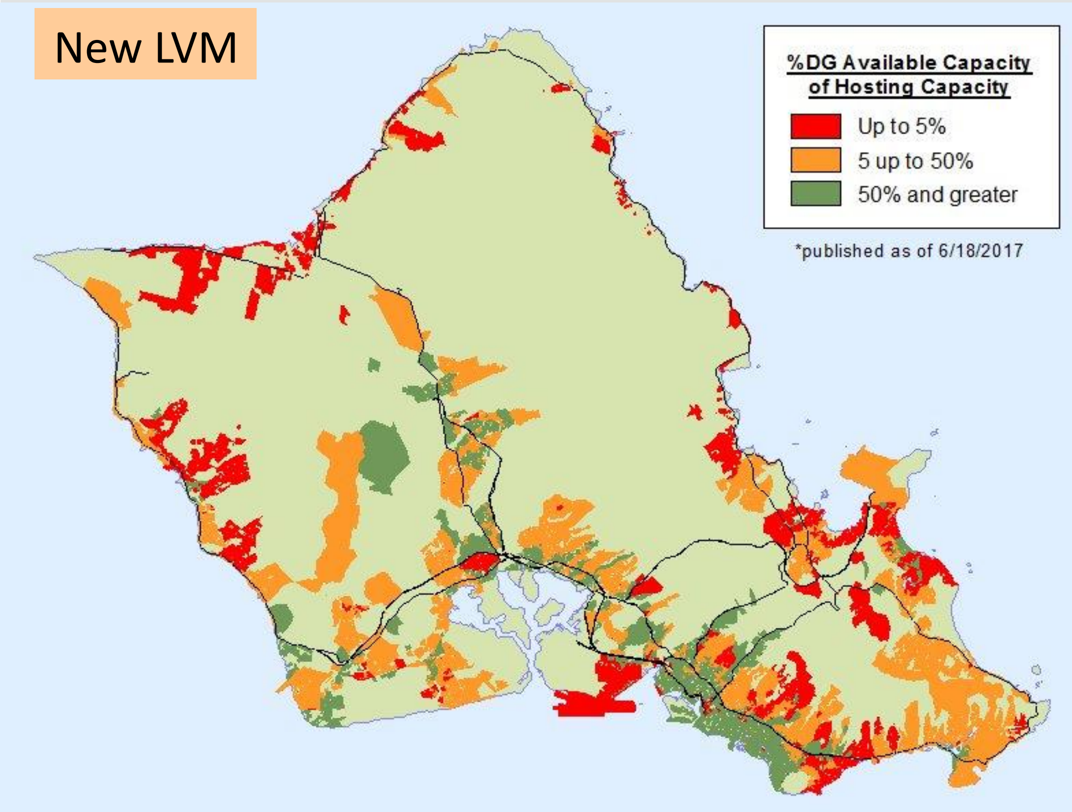




From PG&E DRP webinar

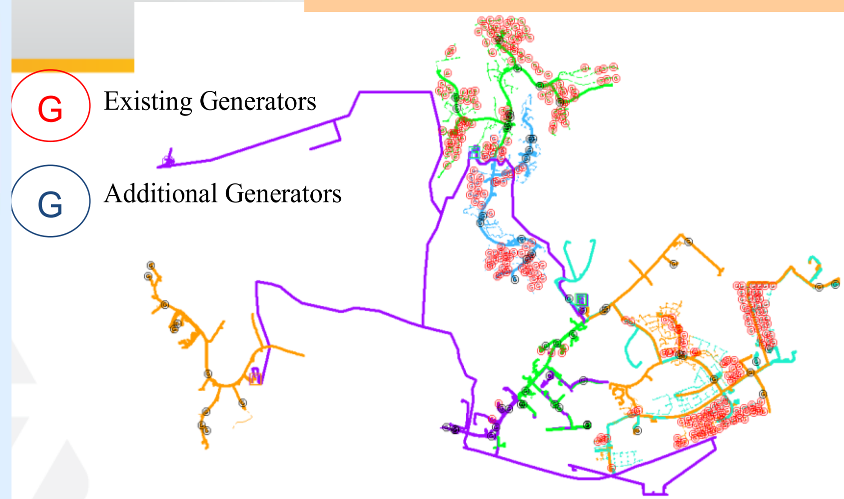
Proactive Approach: Awareness to "See & Inform & Act" Hotspots & Impacts

New LVM

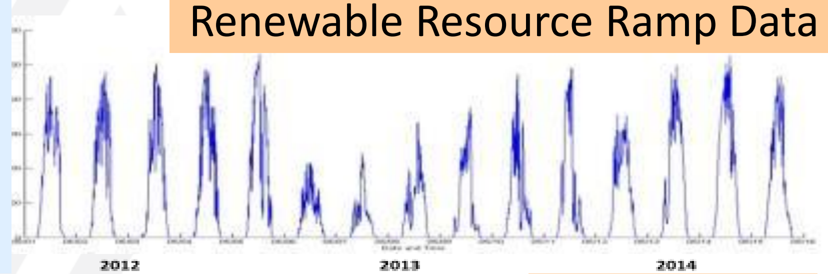


Locational Value Maps showing high penetration distribution areas

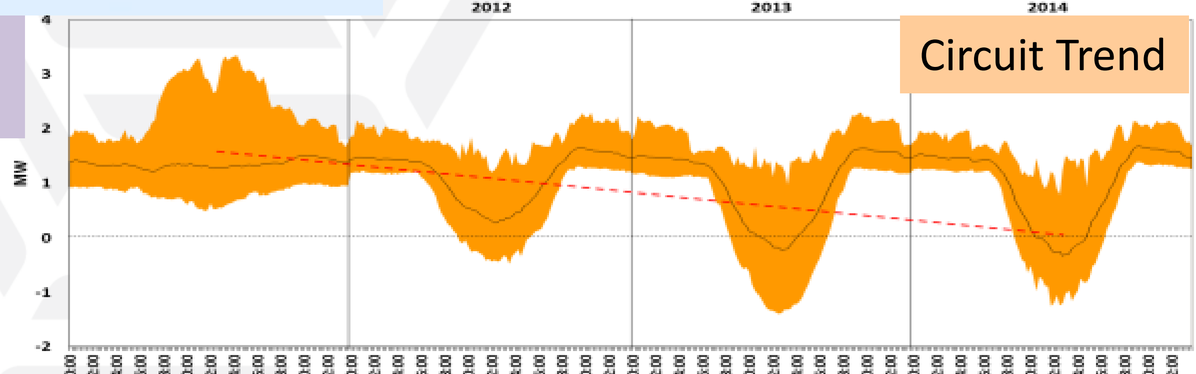
DG Integrated into Model



Renewable Resource Ramp Data



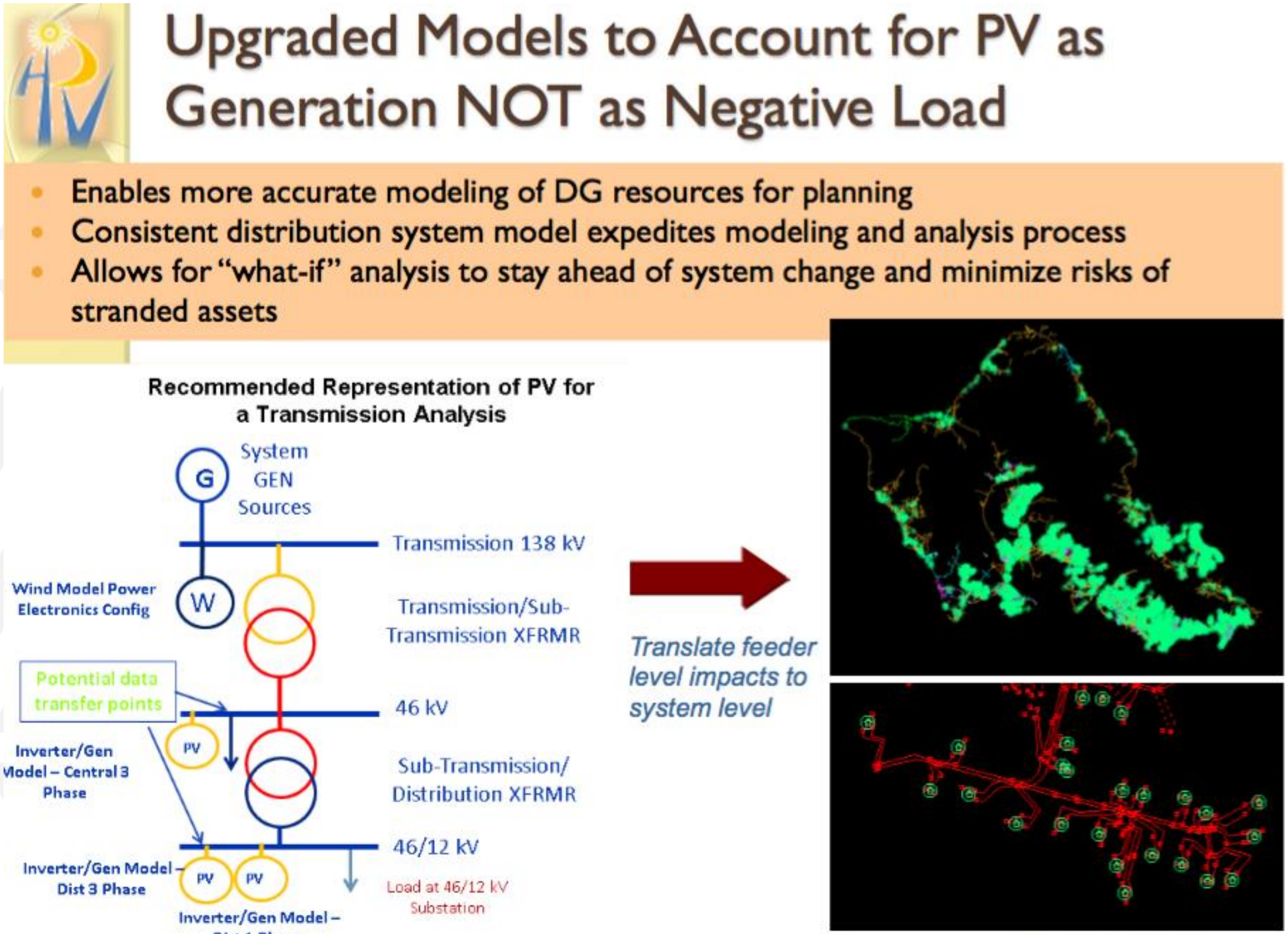
Circuit Trend



"Look for Leading Indicators of change"

Credit: Dora Nakafuji HECO

Hawaii – Enhancing models for mapping of accurate hosting capacity



Source: HECO Hi-PV Study, CSI RD&D 3 Presentation, BEW Engineering

Jeremy Twitchell – Energy Storage Overview

Energy Storage Systems Overview

- Terms for size and costs
- Ownership models
- Utility regulatory environment
- State responses
- Valuation principles and taxonomy
- Additional resources

Storage Terms for Size

- Size is commonly expressed as MW/MWh
- MW – the maximum amount of power that an energy storage system can discharge
- MWh – the maximum amount of energy that a system can discharge from full charge

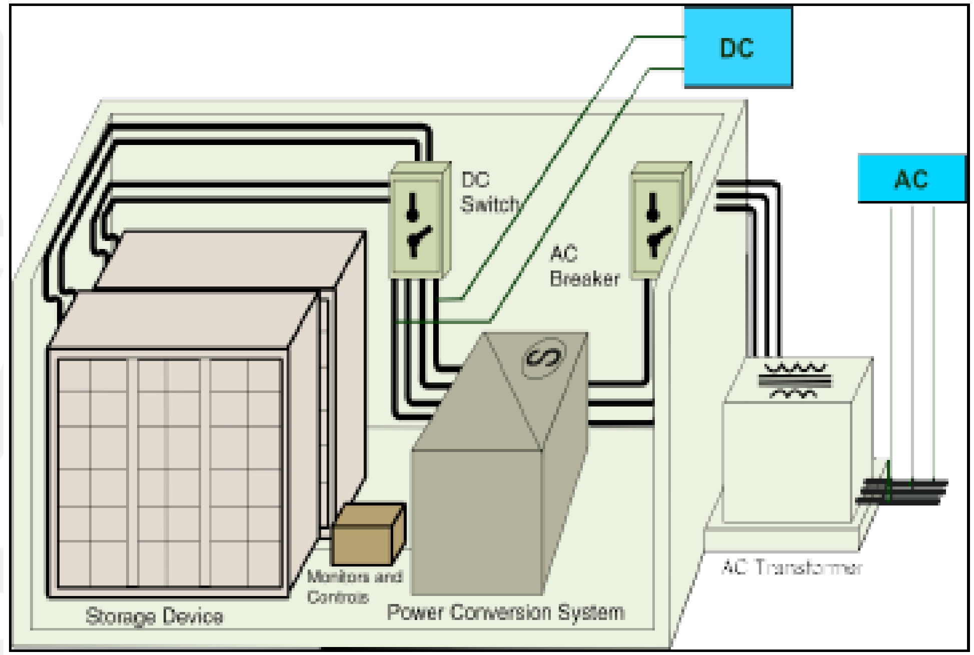
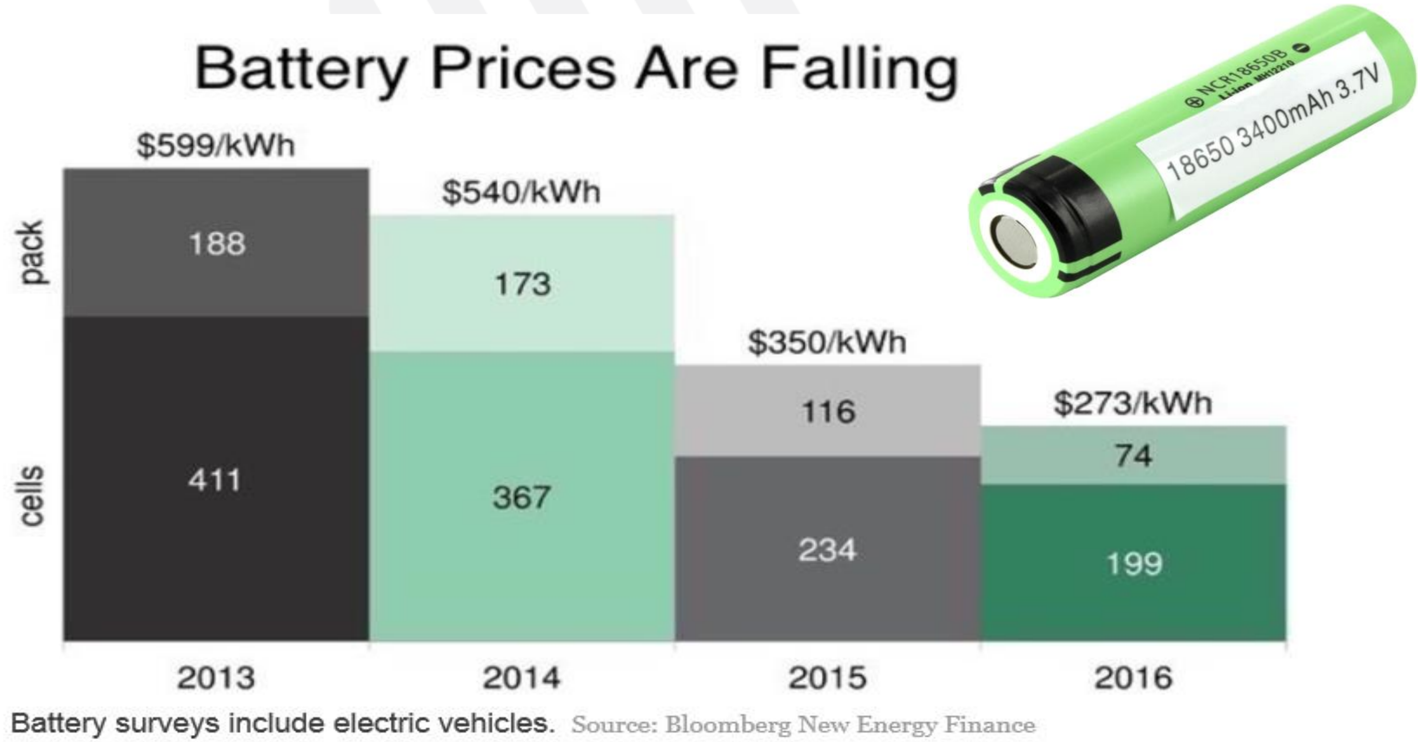


Figure 1. Schematic of a Battery Energy Storage System
(Source: Sandia National Laboratories)

Storage Terms for Costs

- ► Costs can be expressed as $/kWh or $/kWh/cycle
- ► OE Energy Storage Program goal: $150/kWh



- ► Bloomberg: Costs will fall below $200/kWh in 2018 and below $100/kWh by 2026

Energy Storage Ownership Models

- Utility-owned assets
  - More likely to capture portfolio of benefits
  - But it may be difficult to quantify or monetize some benefits
- Engaged customers
  - Commercial/Industrial customers – demand charge management, UPS
  - Residential customers – Backup power, capturing PV generation
- Third-party ownership
  - Typically market-facing assets
  - Limited access points outside of organized markets
- FERC
  - Storage market participation models (Order 841)
  - Facilitating aggregation of distributed storage
  - Cost allocation principles

Uncertainties for Energy Storage in Traditional Utility Planning and Regulation

- Traditional methods for resource planning do not effectively evaluate energy storage
  - Accurate resource characterization and cost attribution
  - System models do not evaluate sub-hourly benefits, locational benefits, distribution system benefits, and customer benefits

- Technology innovation
  - Multiple technology types with various performance characteristics
  - Continuous evolution of costs, performances, and lifespans
  - Regulatory uncertainty

- Core infrastructure – is it generation, transmission, or distribution?

State Responses

- Procurement targets
  - California (2013) – 1,325 MW by 2020
  - Oregon (2015) – 10 MWh by 2020
  - Massachusetts (2017) – 200 MW by 2020
  - New Jersey (2018) – 600 MW by 2021
    - 2,000 MW by 2030
  - New York – Pending
  - Nevada – Pending
- Increased planning requirements
  - Washington UTC Policy Statement
  - New Mexico PRC Rulemaking
- Other approaches
  - Massachusetts: Feasibility study
  - Maryland: Tax credits
  - Colorado: “Storage as a right” legislation

Value Taxonomy

Category	Service	Definition
Bulk Energy	Capacity or Resource Adequacy	The asset is dispatched during peak demand events to supply energy and shave peak energy demand. The asset reduces the need for new peaking power plants and other peaking resources.
	Energy arbitrage	Trading in the wholesale energy markets by buying energy during off-peak low-price periods and selling it during peak high-price periods.
Ancillary Services	Regulation	An operator responds to an area control error in order to provide a corrective response to all or a segment portion of a control area.
	Load Following	Regulation of the power output of an asset within a prescribed area in response to changes in system frequency, tie line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or established interchange with other areas within predetermined limits.
	Spin/Non-spin Reserve	Spinning reserve represents capacity that is online and capable of synchronizing to the grid within 10 minutes. Non-spin reserve is offline generation capable of being brought onto the grid and synchronized to it within 30 minutes.
	Frequency Response	The asset provided energy in order to maintain frequency stability when it deviates outside the set limit, thereby keeping generation and load balanced within the system.
	Flexible Ramping	Ramping capability provided in real-time, financially binding in five-minute intervals in CAISO, to meet the forecasted net load to cover upwards and downwards forecast error uncertainty.
	Voltage Support	Voltage support consists of providing reactive power onto the grid in order to maintain a desired voltage level.
	Black Start Service	Black start service is the ability of a generating unit to start without an outside electrical supply. Black start service is necessary to help ensure the reliable restoration of the grid following a blackout.

Modified from Akhil et al, *DOE/EPRI Energy Storage Handbook*

Value Taxonomy (cont.)

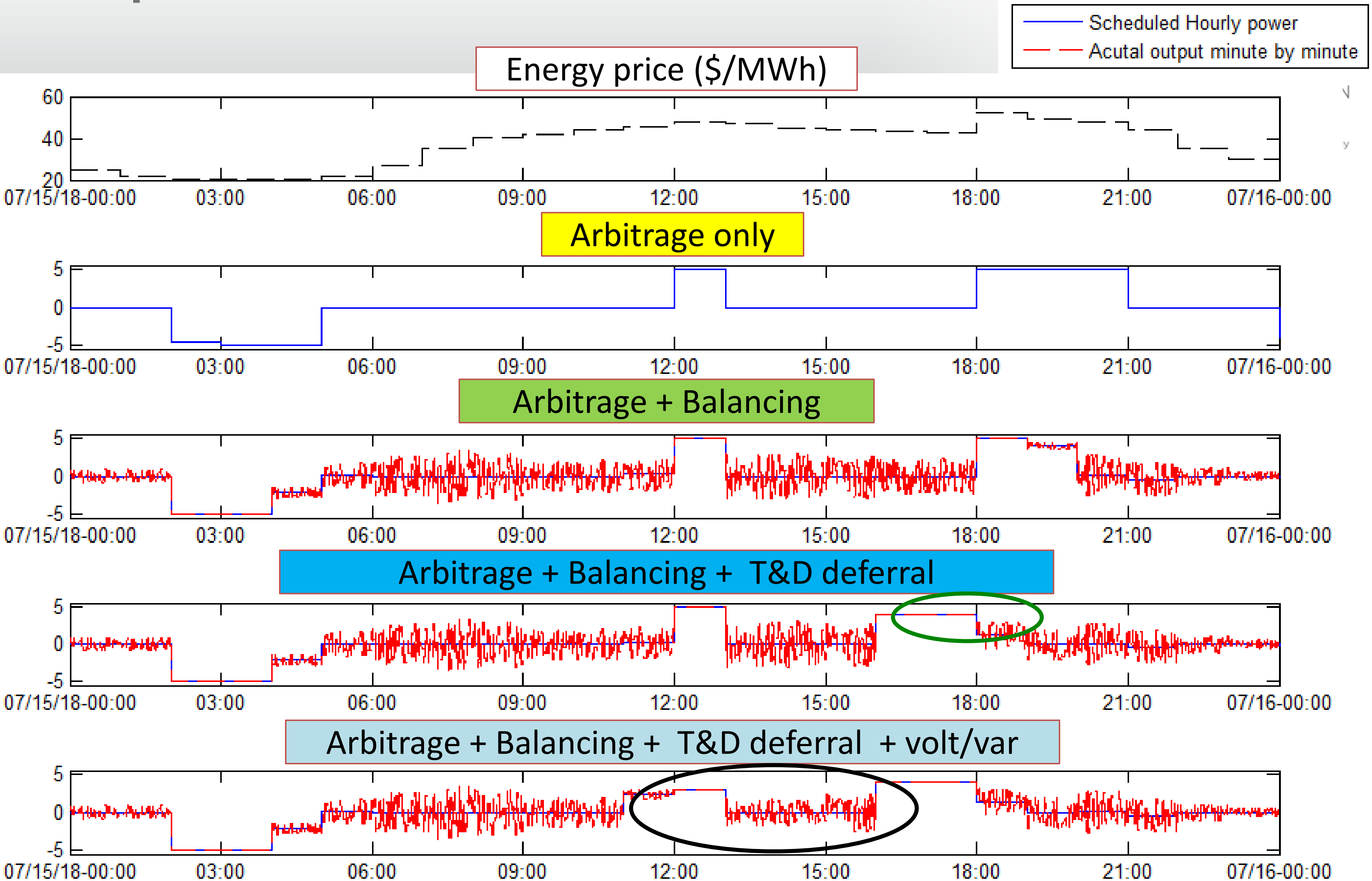
Category	Service	Definition
Transmission Services	Transmission Congestion Relief	Use of an asset to store energy when the transmission system is uncongested and provide relief during hours of high congestion.
	Transmission Upgrade Deferral	Use of an asset to reduce loading on a specific portion of the transmission system, thus delaying the need to upgrade the transmission system to accommodate load growth or regulate voltage.
Distribution Services	Distribution Upgrade Deferral	Use of an asset to reduce loading, voltage, or some other parameter on a specific portion of the distribution system, thus delaying or eliminating the need to upgrade the distribution system to accommodate load growth or regulate voltage.
	Volt-VAR Control	Volt-ampere reactive (VAR) is a unit used to measure reactive power in an AC electric power transmission and distribution system. VAR control manages the reactive power, usually attempting to get a power factor near unity.
	Outage management	Use of an asset to reduce the frequency and duration of outages (avoided lost sales, avoided penalties).
	Conservation Voltage Reduction	Use of an asset to reduce energy consumption by reducing feeder voltage.
Customer Energy-Management Services	Power Reliability	Power reliability refers to the use of an asset to reduce or eliminate power outages to customers.
	Time-of-Use Charge Reduction	Reducing customer charges for electric energy when the price is specific to the time (season, day of week, time-of-day) when the energy is purchased.
	Demand Charge Reduction	Use of an asset to reduce the maximum power draw by electric load in order to avoid peak demand charges.
	Demand Response	Demand response provides an opportunity for consumers to reduce or shift their electricity usage during peak periods in response to financial incentives.

Modified from Akhil et al, *DOE/EPRI Energy Storage Handbook*

Storage Valuation Principles

- **Co-optimization:** Storage can only do one thing at a time, and every action has an opportunity cost. Proper valuation depends on identifying the optimal mix of uses.
- **Performance-informed:** Performance characteristics vary by technology and usage. We're still identifying the relationships between state of charge and efficiency.
- **Discrete values:** When stacking uses, care must be taken to not double count values, particularly when including societal/environmental values.
- **Timeframe for analysis**: The time horizon of an analysis should be equal to the lifetime and life-cycle cost of the proposed set of assets.
- **Location**: Values should reflect local conditions and value streams should be location-, market-, region-, and utility-specific.

Co-optimization



Additional Resources

► DOE Grid Energy Storage Report (2013)
https://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

► DOE/EPRI Energy Storage Handbook
http://www.sandia.gov/ess/publications/SAND2015-1002.pdf

► DOE Global Energy Storage Database
http://www.energystorageexchange.org/